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ABSTRACT

Three papers consider the effect of divestiture on the research and development capacity of Bell Telephone. The first paper, "Forecasts of the Impact of Divestiture on Bell Telephone Laboratories: An Assessment" (David C. Mowery), discusses the operation of Bell Telephone Laboratories (BTL) prior to divestiture in 1984 and reviews forecasts of the impact of divestiture on BTL, in order to compare and contrast the predictions of these two approaches to the analysis of the organization of industrial research. A 35-item bibliography is provided. The second paper, "The Impact of Divestiture on R&D in the Bell System" (A. Michael Noll) (abstract only), discusses the changes in the structure of research and development brought about by the Bell Telephone divestiture, including both the creation of a "new" facility, "Bellcore," to satisfy the research and development needs of the newly separated Bell operating companies, and the simultaneous creation of separate internal research and development capabilities by these companies. The third paper, "The Implications of Diverstiture and Regulatory Policies for Research, Development and Innovation by the Regional Bell Holding Companies" (Robert G. Harris), examines the effects of divestiture on research and development, especially as they contribute to the development of technological innovations. A list of 53 references is provided. (Author/EW)

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Forecasts of the Impact of Divestiture on Bell Telephone Laboratories: An Assessment

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1. Introduction

It is well known that the economist's theory of the firm is actually a theory of markets--theoretical understanding of the basis for the existence of the firm, to say nothing of the factors that determine its boundaries, is not well advanced, despite important work by Williamson (1975), Teece (1982, 1986), and Caves (1982). This theoretical deficiency is particularly significant in the analysis of the organization of research and development. Elsewhere, I have suggested (1983) that the emphasis on the appropriability of the results of research investment that underpins the neoclassical analysis of research and development must be complemented with an analysis of the conditions supporting the utilization of these results.

This paper discusses the operation of Bell Telephone Laboratories (BTL) prior to divestiture in 1984 and forecasts of the impact of divestiture on BTL, in order to compare and contrast the predictions of these two approaches to the analysis of the organization of industrial research. The analysis is complicated by the fact that many of the forecasts of the impact of divestiture were predicated on an outcome that was not realized. The remedy proposed by the Department of Justice in U.S. v. AT&T, the subject of many of these forecasts, differed significantly from the terms of the final settlement (the

Modified Final Judgment, MFJ). The original remedy requested that the regional operating companies be divested by AT&T, which eventually was done, but additionally asked that Western Electric, the manufacturing arm of AT&T, be divested and broken into several independent manufacturing entities. This latter component of the proposed remedy received much of the attention of AT&T witnesses and argument during the litigation. Indeed, the willingness of the Department of Justice to drop its insistence on divestiture of Western Electric ultimately formed the basis for the settlement that terminated U.S. v. AT&T (See Tunstall, 1985).

The first sections below discuss the economics of research investment and provide a brief historical overview of the development of Bell Labs and other U.S. industrial research laboratories. The discussion of the structure of Bell Labs that follows stresses the ways in which the development of BTL was influenced by the need for effective intrafirm transmission of information to support the utilization and commercialization of research findings. Although the Labs' internal structure was influenced heavily by the requirements of knowledge utilization, the characteristically "open" research style associated with BTL, as well as the Labs' intensive pursuit of basic research, appear to have been influenced by the peculiar "appropriability regime" (Teece, 1986) under which AT&T operated during the

1956-1982 period. BTL behavior after divestiture is considered next, drawing on recent work by Noll (1986), followed by a brief conclusion.

2. The economics of R&D: Is appropriability sufficient?

The key elements of the theoretical economic analysis of R&D are contained in papers by Nelson (1959) and Arrow (1962) that considered the economics of knowledge production through industrial research.[1] Research was portrayed in these papers as an activity resulting from investment decisions made by profit-maximizing firms. Nelson and Arrow argued that the social returns to research investment exceeded the private returns faced by the individual firm, a condition leading to underinvestment by the firm (from the social point of view) in research.

The existence of this market failure hinges on the argument, articulated most forcefully by Arrow, that although the firm's costs of investment in knowledge production clearly are substantial, the costs of transferring the knowledge once discovered are effectively zero. This theory provided an important rationale for public support of civilian research and technology, but it is incomplete. Appropriability of research results, although necessary for the encouragement of R&D

investment, is insufficient to explain the success and failure of different organizational forms of research activity. The neoclassical analysis does not address the utilization of R&D results, an issue that is crucial to understanding the organization of research.

The structure and operations of Bell Labs cannot be understood without serious consideration of the role of utilization of technical and scientific knowledge, as opposed to the appropriability of the rents flowing from the exploitation of these results. Nevertheless, this argument must be tempered by the recognition that innovation within the Bell System for much of the past 75 years was influenced heavily by the monopolistic structure of the firm. Although some discussions of the impact of divestiture considered the effects of restructuring the Bell System on internal utilization and communication of research results, many of the predictions of the impact of divestiture employed the appropriability analysis to forecast a dramatic decline in the quantity of BTL research. These latter forecasts, however, overlooked the effects of the modification of the 1956 consent decree's prohibition on entry into new markets on the realm within which the results of Bell Labs research investments could be applied and the rents from these investments appropriated.

3. The development of research within the firm

The appropriability analysis of R&D investment provides little basis for explaining why Bell Labs, like most U.S. industrial research laboratories, was a part of a manufacturing firm. Why did U.S. industrial research consist primarily of in-house research activity, rather than being provided via contract by independent firms?[2] The development of industrial research within U.S. manufacturing was associated with the progressive absorption by large manufacturing firms of functions previously carried out and organized via market institutions, a phenomenon analyzed by Chandler (1977). Indeed, the share of industrial research personnel that was employed in independent research laboratories not affiliated with a manufacturing firm, organizations engaged in the sale of R&D services, declined through much of the 1920-45 period.[3]

The impending expiration of patents covering key product technologies also played a central role in the foundation or reorganization of in-house research facilities by AT&T, Eastman Kodak and General Electric.[4] In-house research functioned as an important mechanism to bolster these firms' patent portfolios, and influenced the purchase of patents from external sources during the early 20th century.[5] Patenting strategies declined somewhat in importance within many leading industrial research facilities after their foundation. The reduced

significance of patents in the R&D strategies of many firms was associated with the development of a strong firm-specific knowledge base that was not patentable, but served nonetheless as a barrier to the entry of competitors.

In-house research allowed for the development and exploitation of firm-specific knowledge, reflecting the fact that intrafirm communications were superior in quantity and quality to those operating among contractual partners, as well as the fact that production and the acquisition of detailed technical knowledge frequently are joint activities. An in-house research laboratory also was better able to exploit the advantages of interactions and communications among the various stages of the innovation process, an important factor in successful innovation and technological development. How did Bell Labs exploit these characteristics of in-house research, and what were the predicted impacts of divestiture on the exploitation by Bell Labs of these links and characteristics? These issues are considered in the following sections.

4. Bell Labs before divestiture

Prior to the 1984 reorganization and divestiture of the regional operating companies by AT&T, Bell Labs represented the largest single industrial research organization in the U.S.,

employing 25,000 persons and spending more than $2 billion annually. Roughly 50% of this budget came from Western Electric for specific development projects, and another 15% was derived from the Federal government and contracts with the Bell operating companies for the development of business information systems. Nearly 35% of the Bell Labs operating budget, however, came from the "license contract" between AT&T and the Bell operating companies, which obligated AT&T to "prosecute continuously fundamental work of research, investigation and experimentation in the development of the arts and science of telephony..."[6]

As of 1974, the contract called for the operating companies to contribute a maximum of 2.5% of operating revenues to AT&T for support of "research and fundamental development." The Congressional Office of Technology Assessment noted that this stream of revenues for the support of fundamental research

> ...provided a regular source of income that could be counted on year after year...AT&T was free to use those funds much as a government might use tax revenues, allocating some portion of those revenues to support activities that were for the general good but provided no immediate commercial benefit. (Office of Technology Assessment, 1984, p. 129).

License contract revenues supported the growth within Bell Labs during the postwar period of basic research, many of the results of which were published in the open scientific literature. Nearly 10% of the Bell Labs budget was devoted to basic research, and Lab scientists received seven Nobel Prizes, as well as numerous other awards. According to the written testimony of William Nordhaus, a witness for the defense in U.S. v. AT&T, "...AT&T is unique in its publication record; it has by far the largest number of scientific publications of any American firm in the journals covered by ISI [the Institute for Scientific Information]. The 1781 publications [during 1973] of AT&T were followed by 866 by IBM." (Nordhaus written testimony, 1981, p. 76).

The "open" research style characteristic of Bell Labs during the postwar period, of course, also was affected by the 1956 consent decree that had settled the previous Federal antitrust suit against the Bell System. Under the terms of the consent decree, the Bell System was prohibited from entering other areas of business, such as semiconductor components or computers, and Bell Labs was ordered to license all patents at low royalty rates. The 1956 decree gave Bell Labs little or no incentive to restrict the diffusion of research findings that affected other industries. Moreover, AT&T throughout the

postwar period held a commanding position within telecommunications, based in large part on its integrated structure, and had little to fear from imitation by other telecommunications equipment manufacturers or service providers. This consent decree was modified considerably by the settlement in 1982 of U.S. v. AT&T, which removed both the prohibition on AT&T activities in non-telecommunications businesses and the licensing requirement.

The internal structure of BTL reflected efforts to exploit advantages of the large size of the research enterprise. BTL relied on an elaborate internal division of labor that exploited the opportunities for interaction between persons or departments involved in different phases of a research and development project.

Interactions between basic and applied research, as well as between research and development activities, played an important role in Bell Labs innovation. The importance of these interactions reflects the fact that the innovation process is not a linear progression from basic research to commercial production. Instead, innovation consists of a sequence of linked, interactive stages, within which feedback from applied research affects the basic research agenda (See Rosenberg, 1982, and Kline and Rosenberg, 1985, for further discussion). Many of

Bell Labs' most significant basic research advances resulted from problems that originated in the applied technology of telecommunications. The early development of radioastronomy in the 1930s by Jansky, for example, was motivated by the problem of background noise in long-distance signals. Continued research into this aspect of telecommunications technology led to a Nobel Prize for Arno Penzias and Robert Wilson of Bell Labs in 1978 (See Rosenberg, 1982).

BTL continually reorganized its structure and research agenda to accommodate changes in telecommunications technology. As technological interfaces within telecommunications changed, Bell Labs developed new organizational structures and new technological specialties (e.g., systems engineering). The development of the #4 Electronic Switching System, for example, led to a shift in the location of much of the research and engineering in switching technologies from Columbus, Ohio, to Indian Hill, Illinois. This development project also required much closer integration of research and engineering activities in switching and transmission, as well as the development of expertise in software engineering and computer architecture within the Bell Labs-Western Electric switching research and engineering organizations (See Lane, Beddows, and Lawrence, 1981, Ch. 6).

Another longstanding BTL policy stipulated that the development of research discoveries was to be carried out by a development group separate from the group responsible for the original research. Although this division of labor undercut some of the advantages derived from the close interaction between scientific and purely technological concerns and problems noted in the previous discussion, separation of development from research tasks also prevented the energies of research personnel from being squandered on applied or development activities.[7] The organizational separation of research and development functions also meant that the development staff functioned as a liaison between the research and manufacturing processes.

Separation of research and development functions did not imply, however, a lack of interaction between development and research personnel and activities. The research team responsible for the discovery at BTL of the transistor, for example, was extensively involved as consultant and advisor with the BTL development group throughout the late 1940s and early 1950s. These communications were aided by the longstanding policy of locating BTL development and research personnel concerned with a given technology in the same buildings and laboratories.[8]

The development of the Branch Laboratories of BTL illustrates the importance of intrafirm communications in the innovation process, the interaction between technology and the requirements for such communications, and the efforts of the Labs to accommodate these changing requirements. The Branch Labs are BTL research facilities housed within Western Electric manufacturing plants. Instituted after World War II in Western Electric plants devoted to the manufacture of then-novel electronic components, the Branch Labs were intended to improve the quality and quantity of communications between the group responsible for research and development and those charged with manufacturing and process design. The Branch Labs were staffed largely by development personnel--the Labs provided technological support for product development and manufacture, rather than focusing on fundamental research.

The Branch Labs were proposed by Mervin Kelly, vice president for research at AT&T, in 1943. According to Kelly, the increased importance of electronics technologies and components (e.g., tubes) had two implications for Bell System R&D. Reliance on electronic components meant that the Bell System would in the future utilize components employed in other industries, notably radio and television communications. Manufacture of these components by Western Electric would have to meet the cost performance of suppliers in other industries:

> We are certain to have manufacturing costs challenged to a greater extent than ever before. The incidence of this situation, with 'yard sticks' of a sort at hand, supplied by the products of our 'related industries,' for unsound as well as sound comparisons, make it imperative for us to review carefully our procedures of development, design, engineering for manufacture and manufacture. All of these sectors contribute in a complicated, inter-related way to our apparatus cost picture. (1943, p. 6).

Cost-effective manufacture of such components posed novel technical challenges, reflecting the fact that these devices then typically were produced in small batches, as well as the fact that both the cost and the technical performance of semiconductor components were sensitive to manufacturing processes.[9]

Writing prior to the 1956 consent decree, Kelly also expressed concern about the possible utilization of the findings of Bell Labs' basic research by competitors from "related industries". The rapid dissemination of Bell Labs basic research results made it imperative that the research organization move into production of new devices or components as rapidly as possible:

> It is well to bear in mind that the results of our basic research and development program, which are in general so well done, will be available to other organizations without much time delay and with very few restrictions. This adds emphasis to the need for our making the design-to-manufacturing sector of our effort as uniquely creative, efficient and fast moving as is possible. (p. 12).

Kelly's statement illustrates the interaction between the external appropriability environment and the requirements for rapid intrafirm knowledge transmission and utilization. In order for lead time and "first-mover" advantages to enable BTL to capture the returns from innovation, reorganization of the internal structure of the Labs was necessary.

The discipline and Department of systems engineering also played an important coordinating function within Bell Labs through much of the postwar period. The size and complexity of the telecommunications network placed a premium on the maintenance of compatibility and systemwide interoperability. Many of the analytic techniques of systems engineering were developed at Bell Labs in order to ensure network compatibility and integrity, according to the defendant in U.S. v. AT&T:

> In satisfying network needs, Bell Laboratories must assure that new products, systems and services are competible with existing and contemplated technology. Bell Laboratories systems engineers must understand and take into account future technological trends and the costs of manufacture, installation, operation, maintenance and repair, and understand the technical and physical environment in which its designs will operate, including reliability requirements as well as the limits and potential of the manufacturing process. As a result, they work closely with Bell Labs research and development groups and with Western, AT&T, and the operating companies. (Plaintiffs' Third Statement of Contentions and Proof, p. 1432)

Systems engineers operated as an organizational link between network requirements and the research and development activities of the Labs, just as the Branch Laboratories linked the manufacturing and research activities of the Labs and Western Electric. For a number of years, the systems engineering activities of Bell Labs were organized as a separate Department, with responsibilities for the full range of network products and activities. In 1972, however, the Department was dissolved, and individual departments within the Labs assumed systems engineering responsibilities. The dispersion of systems

engineering activities was undertaken to improve the responsiveness of Bell Labs product development activities to market demands and requirements, and followed moves by the Federal Communications Commission (the Carterfone decision) to open the telecommunications equipment market to competition from non-Bell System producers. Although no evidence exists suggesting a direct link between Carterfone and this reorganization, it is likely that the erosion in Bell System market power resulting from Carterfone reduced BTL's ability to reap the profits of innovation. Decentralization of systems engineering responsibilities was one means to get new products to market more rapidly and exploit lead time advantages more effectively.

The changing role of patents within Bell Labs provides another illustration of the links between appropriability and internal laboratory management and structure. The development by Bell Labs of a firm-specific body of knowledge gradually diminished the importance of patents within BTL research during the first 50 years of the Labs' history. Rather than patents alone, the development by the Labs of new techniques for research and management of technological development became central to innovative performance.[10] Examples of such firm-specific bodies of knowledge include the algorithms developed by Harold Black in his studies of the behavior of

electronic waves, and the management and analytic techniques of systems engineering. In addition, much of the early theory of solid-state physics was developed within the confines of the Labs. As one BTL employee noted,

> ...the knowledge gained in producing nominal products of R&D is largely captured by the researchers themselves and spills over into future R&D as well as R&D in neighboring fields. If the researchers work for an outside contractor or grantee, these knowledge spill-overs or 'externalities' are likely to be lost to the firm. Having the employee work for the firm helps the firm capture the knowledge...Contracting research to outsiders lessens the firm's ability to hire the best talent, but, perhaps more importantly, lessens the firm's control over the optimum use and development of the human capital doing work in fields of importance to the firm. (Zajac (1976), p. 21)

Bell Labs prior to 1984 supported an extensive basic research program that made significant contributions in both telecommunications and broader scientific knowledge. The internal structure of the Labs was designed to maximize the advantages of communications between the group charged with development and that in charge of research. Organizational

separation of these functions was combined with physical proximity, in order to enhance the productivity of the research process. This organizational principle was also applied to the Branch Labs. In addition to supporting intrafirm communications, Bell Labs over time developed a considerable body of nonpatentable, partially codified knowledge and analytic expertise that formed a sort of research and development "process technology" that was unique to the Bell System. How was the performance of BTL affected by the horizontally and vertically integrated structure of the Bell System, and how did the appropriability regime affect BTL's performance? These questions, which underpinned the assessments of the impact of divestiture, are considered in the next section.

5. Forecasts of the impact of divestiture

The assessment by witnesses and others of the effects of a reorganization of the Bell System on Bell Labs focused on both changes in the appropriability of the returns from research and the disruption of internal information flows and communications that could result from divestiture. Since most of these predictions were developed in the course of litigation, they occupy a status somewhere between that of scientific evidence and unsupported assertion. Although a great deal of the testimony in U.S. v. AT&T dealt with the impacts of divestiture

on innovative performance, much of this discussion concerned the quality of local and long-distance telecommunications services, rather than the quality of the research activities of AT&T. The changing nature of the remedy proposed by the Department of Justice also complicated the discussion. This discussion of forecast impacts begins with a discussion of the assumptions concerning the links between Bell System structure and Bell Labs performance that underpinned the projections. A discussion of the forecast impact on Bell Labs of the divestiture of Western Electric is followed by a consideration of the impacts on Bell Labs of the divestiture of the regional operating companies.

a. The relationship between the structure of the Bell System and the performance of Bell Labs

The testimony of William Nordhaus provides a clear statement of the appropriability arguments relating the performance and character of Bell Labs' research to the vertically and horizontally integrated structure of the Bell System. According to Nordhaus, the structure of the Bell System was essential to the ability of Bell Labs to appropriate the benefits of its massive research investment, particularly basic research. This ease of appropriability allowed Bell Labs to exploit economies of scale within the research process, and reduced the severe uncertainties that otherwise hamper

investment in innovation.

The appropriability of the rents from Bell Labs' basic research was enhanced, according to Nordhaus, by the joint provision of telecommunications services and equipment by the Bell System. This feature of the Bell System's structure meant that the results of a vast range of research activities could be disseminated widely and still yield a considerable payoff for the Bell System:

> ...the fruits of basic research are extremely difficult to appropriate, so little basic research is financed by medium and small firms. Because Bell is integrated, however, it can harvest a sufficient fraction of the fruits of basic research in its own services, even when its basic research is used by other equipment manufacturers who sell their improved products to the Bell system. Indeed, the "downstream benefit" is so significant in the Bell System and relates to such a large proportion of the Bell System's total investment that the integrated structure provides an incentive to share the fruits of basic research with other manufacturers. Shared basic research is translated more swiftly and efficiently into equipment that benefits the downstream service entity. (Nordhaus, pp. 35-36)

As Rosenberg pointed out in other testimony on behalf of AT&T (1982), the structure of the Bell System prior to 1984 also increased the payoff from BTL research in a diverse array of disciplines, from psychology to cosmology to economics.[11]

According to Nordhaus and other witnesses, the high costs, indivisibilities, and uncertainties of telecommunications research and development favored large research installations--significant economies of scale and scope existed within telecommunications research and development. The large size of Bell Labs therefore was essential to rapid technological progress. Moreover, the license contracts with the operating companies, as well as the flow of funds from Western Electric for development work, provided an effective means for the finance of large-scale basic and applied research.

Nordhaus, however, also stressed the importance of utilization of research results within the Bell System in discussing the unrestricted flows of information and technical data among researchers, equipment designers and producers, and the downstream "users," the operating companies. The importance of these internal flows of information stemmed from the network characteristics of telecommunications technology and the rate of change in this technology:

> Generally, detailed knowledge about the characteristics of a complex technology or system is primarily available to the users of the system--in this case the operating companies. Thus, the uses and needs of the system will be embodied in the knowledge of the skilled personnel of users, while the technical possibilities for new products and services are embodied in the knowledge of scientists and engineers of the R&D establishment and manufacturing branches in the industry. Such dispersion of knowledge would be of less moment in an industry where the technology was moving slowly, in which more of the technical change was embodied in products, or in which there were less technical connectedness. In telecommunications, however, because each of these three elements is present, it is of great importance for rapid technical change in telecommunications that service, manufacturing, and R&D personnel be able to exchange their specialized knowledge quickly and freely within the boudnaries of the firm. (Nordhaus testimony, pp. 50-51)

These assertions about the influence of Bell System structure on the appropriability and efficiency of utilization of BTL research results rest on several assumptions and assertions for which evidence is weak or absent. There is

little empirical evidence, for example, to support the apparent assumption by both Nordhaus and Rosenberg of the existence of economies of scale within the R&D process. As Fisher and Temin (1977) have pointed out, this proposition has not been tested rigorously. Nor do empirical studies support the hypothesis that large firms invest proportionately more in R&D than small firms (See Cohen, Levin, and Mowery, 1987); industry conditions appear to be far more significant than firm size in determining R&D investment.

The argument that the relatively open character of Bell Labs research was dependent on the horizontally and vertically integrated structure of the Bell System also must be qualified by the recognition that during much of this period, the Bell System was compelled by the 1956 consent decree to license its innovations widely. The internal communications and flexibility of the Bell Labs-Western Electric-operating companies-AT&T complex undoubtedly contributed to innovative performance, but at least one independent study commissioned by the Federal Communications Commission suggests that the Bell operating companies were not always satisfied with the responsiveness of Bell Labs to their requirements.[12]

b. The impact on Bell Labs of the divestiture of Western Electric

Any change in the structure of the Bell System would affect both the appropriability of the rents from innovation and the relationships among the various components of the research and user organizations. The two proposed remedies in U.S. v. AT&T, calling respectively for divestiture of Western Electric and divestiture of the regional operating companies, were projected by observers to have different effects on Bell Labs. Both sets of forecasts, however, stressed the impact of changes in the market on the size of the BTL research budget, thus invoking one form of the appropriability arguments. These projections also highlighted the utilization issue, emphasizing the potential of a structural remedy to increase barriers to the flow of information and technical data and reduce research efficiency.

The divestiture of Western Electric received considerable attention in the early statements of evidence and stipulations of the plaintiff and defendant in U.S. v. AT&T. The purely financial implications of divesting this unit were significant for Bell Labs. Western Electric funding, after all, had been devoted largely to specific development projects. Although the divestiture of Western might indirectly reduce the size of the

basic research program funded through the license contract, as license contract funds were devoted increasingly to systems-related development projects, this effect received little attention during the litigation. Testimony and analysis from AT&T witnesses instead focused on the implications of divestiture for the efficiency of the systems development and procurement processes.

The importance of in-house research expertise for telecommunications equipment development and production was such, for reasons noted previously, that the relationship between Bell Labs and Western Electric contributed to the efficiency and quality of technological change within the Bell System. Opponents of the divestiture of Western Electric argued that this step would not only impair the quality of telecommunications equipment, but would also undercut the effectiveness of Bell Labs' research activities:

> The Government's proposed relief would fragment Bell Laboratories--the world's foremost industrial laboratory. The proposal to divest Western and the "allied research and development" of Bell Labs...presumably would separate Bell Labs' applied research and product development activities from its basic research and systems engineering activities. This

> split between the owners of the network and its suppliers would mark the end of the fruitful collaboration among these activities that underlies Bell Labs' unmatched record of advances in basic research and new product and system development. No longer would the thinking of the basic researchers and systems engineers be focused and sharpened by association with applied researchers and product developers. No longer would the work of these latter groups be enriched by close relationships with those producing basic advances in science and understanding of network needs. The lack of common purpose resulting from such fragmentation would inhibit the effective exchange of proprietary information necessary to match network needs with technological opportunities. (Defendants' First Statement of Contentions and Proof, pp. 441-442)

In this view, the dissolution of the links between basic research, systems engineers, and equipment design and production would narrow the range of basic research issues and questions, reduce the integrity and compatibility of equipment developed for the network, and lead to the balkanization of the national telecommunications system.

Within Bell Labs, divestiture of Western Electric would

lead to a smaller overall research budget, as well as a decline in the efficiency and productivity of research. The loss of a portion of Nordhaus's "downstream benefit mechanism," which enabled Bell Labs to reap the returns from its research, would reduce the level and the openness of Bell Labs research. Within the telecommunications network, the divestiture of Western would reduce network integrity and procurement efficiency. The development and procurement of telecommunications equipment for the Bell System, according to one witness, would come to resemble the defense procurement process, with unfortunate consequences:

> ...the Bell Operating Companies apparently would have to contract as DOD does, on the basis of competitive proposals submitted by a variety of non-integrated, competing manufacturers, for the development of innovative, complex products for the network. The process of contracting for research and development of products to fill perceived needs would also presumably have to take a form of competitive procurement similar to that of DOD. This would result in the same kinds of problems that DOD encounters in its nonroutine procurements. The operating companies, like DOD, would probably try to remedy those problems by applying the same kinds of solutions that DOD has tried, with limited

success, all of which are designed to achieve the benefits inherent in integrated procurement. (Betts written testimony, U.S. v. AT&T, p. 26)

c. The consequences for Bell Labs of the divestiture of the regional operating companies.

Divestiture of the regional operating companies was mandated in the settlement of U.S. v. AT&T and implemented in 1984. The predictions of the impact on Bell Labs of this structural change made during and after the litigation concern the efficiency and effectiveness of the equipment procurement process, the integrity of the telecommunications network in the absence of the Bell Labs systems engineering leadership, and the changes in the level and characteristics of Bell Labs research.

Divestiture of the regional operating companies meant the loss of a large source of funding for basic research for Bell Labs. The end of the license contract revenues, according to a number of witnesses, would reduce the level of basic research and diminish the ease and speed with which this research was commercialized or otherwise made available to the outside world. A central portion of the "downstream benefit mechanism" having been lost, Nordhaus argued, Bell Labs would focus on short-term, equipment-related research, and might reduce even

the applied research budget:

> The loss of the license contract is serious because these funds account for over 80 percent of the current funding of research and systems engineering in Bell and 50% of all basic research in the communications equipment industry. Because the new Long Lines will be only a small fraction of the size of the telecommunication service operations of the current Bell System, there is reduced incentive or ability to finance research...
>
> In addition, the user-directed elements of Western-financed development will be largely lost in the remedy. The Bell Remnant [the divested AT&T, Long Lines, and Bell Labs] will tilt much more toward a conventional equipment manufacturer, and it will therefore have relatively greater incentives to invest in R&D that will enhance its equipment sales and profits than in systems of non-product embodied R&D. Moreover, the Bell Remnant will no longer have any incentive to fund R&D that benefits the divested Operating Companies at the expense of Western or Long Lines, even though ultimate costs ofservice might be lower. Thus it is expected that the size of the funding of Western's development effort will shrink, and its direction will change toward hardware

projects. (Nordhaus written testimony, p. 97)

Other opponents of divestiture argued that in addition to producing a smaller research effort that included less basic research, this policy would mean the loss of Bell Labs' systems engineering services for a considerable portion of the network.[13] The contractual and organizational difficulties of cooperative research were so great as to prevent the establishment of a cooperative systems engineering effort:

> ...it is highly unlikely that anything would take the place of the license contract, for contracted company-financed R&D simply is not performed in substantial amounts in the U.S. today. As explained above, the reason why contract R&D is so rare is that the difficulties of appropriability, indivisibility, and uncertainty make R&D extremely difficult to manage outside an integrated firm. Further, the ability to take advantage of economies of scope in related large research projects would be lost in an environment of arms-length contracts. (Nordhaus testimony, p. 96)

The absence of such a "network custodian" would reduce the integrity of the U.S. telecommunications network.

d. The impact of divestiture: evaluating the predictions

Although nearly three years have passed since divestiture at this writing, it is still too early to assess the complete impact of divestiture on the operations and efficiency of Bell Labs. Preliminary indications suggest that the predictions of plummeting research budgets at BTL were incorrect. Far less is known, however, about any effects on the breadth of the research agenda and dissemination of the findings of the Labs. The effects of disruption of the channels of communication between the operating companies and BTL, as well as any balkanization of the national telecommunications network, cannot yet be determined. The operating companies have proven capable thus far of cooperating in the foundation and operation of Bellcore, a joint research organization serving the systems engineering and equipment procurement needs of the operating companies. Significant tensions have developed among the regional operating companies, however, over the level and direction of Bellcore research.

One of the most important changes in the competitive environment of AT&T and Bell Labs, of course, is the lifting of the 1956 consent decree. Bell Labs and AT&T now are free to pursue a more restrictive licensing policy, which may contribute

to a less liberal policy on the disclosure of research results at the same time that it restores some of the appropriability mechanisms whose loss was predicted by Nordhaus. Indeed, the ability of AT&T to enter businesses that previously had been foreclosed may expand the profitability of basic research, since the results of such research are likely to be relevant to a wide range of products and processes that Bell Labs and AT&T can produce commercially (See Nelson, 1959, for the classic argument).

According to Noll (1986), AT&T since divestiture has been spending far more, relative to its size, on R&D than was true of the pre-divestiture period. This surge in spending reflects the costs of efforts to enter new markets, such as computers. Noll's discussion, however, does not consider the changes in the research agenda of Bell Labs that may have occurred since divestiture. Research in economics, psychology and other areas has been reduced, but other areas of basic research have experienced significant increases. Dissemination of research findings, according to BTL managers interviewed by Noll, continues to be liberal. This claim is virtually impossible to evaluate, however, and recent Bell Labs work in linear programming algorithms in fact does appear to have been disseminated less widely than might have been the case prior to 1984 (See Business Week, 9/21/87). The greatest dangers to

continued high levels of research investment by AT&T may be the lack of profitability in these new business areas, rather than any disincentives for R&D investment resulting from the firm's divestiture of the regional operating companies.

The regional operating companies have defied predictions not only in their profitability, but also in their willingness (thus far) to support a cooperative research organization (Bell Communications Research, Bellcore) charged with responsibility for network systems engineering. As the Office of Technology Assessment noted (1984), Bellcore's incentives to disseminate the results of its research are strong, since it operates as an agent for the user firms in testing and evaluating equipment for purchase by the operating companies. The possibility that the regional operating companies may enter into the production of telecommunications equipment or the provision of a wider range of value-added services, however, may change the role and operations of Bellcore. One regional operating company (U.S. West) has suggested that it may withdraw from the cooperative enterprise (Roberts, 1987).

Noll (1986) concludes that the impact of divestiture has been to increase AT&T's R&D spending. The report of the Office of Technology Assessment, published as the settlement was being implemented, noted the numerous offsetting factors that affect

Bell Labs research and concluded that

> ...it is still too early to tell whether the quality or direction of research at Bell Labs will be adversely affected by deregulation and divestiture, or whether any changes in its research would have major repercussions for U.S. research as a whole. (Office of Technology Assessment, 1984, p. 134)

This assessment remains essentially valid. There is insufficient evidence to evaluate the impacts of divestiture on the internal operations and efficiency of Bell Labs. The negative predictions of the appropriablity analysis of divestiture's impact on Bell Labs' R&D investment, however, appear thus far to be wide of the mark.

6. Conclusion

The existence of Bell Labs, like most other U.S. industrial research laboratories, reflected the importance and effectiveness of intrafirm, as opposed to interfirm, channels of communication and technology development for innovation. Unlike many other industrial research laboratories, however, Bell Labs developed a strong program of basic research, as well as a relatively liberal policy towards the dissemination of research

results. Bell Labs also displayed an unusual ability to adapt to the requirements of telecommunications technologies, developing new areas of scientific inquiry and reorganizing its research activities to respond to new technological and scientific opportnities.

The structure of the telecommunications industry that is emerging from the settlement of U.S. v. AT&T preserves considerable incentives for AT&T to maintain a large basic and applied research organization. The loosening of the restrictions imposed by the 1956 consent decree has opened up significant business opportunities for AT&T in the research-intensive areas of computers and business equipment, offsetting reduced incentives for R&D investment. The character of the research funded within Bell Labs, however, as well as the speed and efficiency with which research results are translated into commercial products or published in the open literature, nevertheless may be affected adversely by this structural change.

Bell Labs during the postwar period was an important national scientific asset, conducting basic research in a wide range of areas and rapidly disseminating the results of this research. From the viewpoint of economic efficiency, however, the use of the national telecommunications network as a

mechanism for the provision of an important public good (basic research), is a policy of questionable merit. From the viewpoint of political feasibility, the ability of the Federal and state governments to fund basic research in sufficient quantities to offset the putative market failure in this area was very questionable--Bell Labs thus represented an interesting quasi-public institutional compromise for the support of basic nondefense research, the likes of which will not be seen again soon within the U.S. economy.

NOTES

1. These paragraphs draw on Mowery (1983a).

2. Mowery (1981) provides a quantitative analysis of early trends in employment growth and laboratory formation.

3. See Mowery (1983b) and below for further discussion.

4. See Reich (1983); Jenkins (1975).

5. See Reich (1977, 1980).

6. Cited in Touche, Ross (1974), Exhibit 1, p. 3.

7. "The Laboratories considers the complete segregation of research into a single organization the most essential and constructive step in maximizing the productivity of its research...The Laboratories' judgment of the importance of this integration of all research and its organizational separation is based on earlier experience with other patterns of organization. Many years ago, for example, I was responsible for all electronic research, development, and design. Other areas were similarly grouped, giving a number of parallel organizations each operating across the entire range of creative technology. In this pattern it was not possible to create and maintain the atmosphere and environment conducive to highest productivity in research. it was not possible to protect the research programs from 'raids' in support of tightly scheduled development programs. Development did benefit, in an immediate sense, but in the long term it did not gain by its more intimate association with research. Recruitment and retention of highest quality research men were made more difficult by this pattern of organization and work." (Kelly, 1955, pp. 4-5).

8. Along with other important organizational innovations, the principle of co-location of development and research personnel concerned with a given technology grew out of the Labs' initial experiences with electronics. Writing in 1943, Kelly noted "...the great value of intimate space contact between research, development and design work in some of the new technologies, such as electronics. It is most desirable that, in the movement of organizations to Murray Hill, we not only do not lose this contact in groups where we have had it, but that we make it general as soon as we can." (p. 9).

9. "In the development design sector where the Laboratories dc important process development work that is essential to the

evolution of the new apparatus, they do not have the advantage of adequate contact with the manufacturing [sic] because of separation. But even more important, since manufacturing process is a responsibility of the Engineer of Manufacture, the laboratory work in many instances is done with little regard to the process that is later to be developed for manufacture. During the past ten or fifteen years apparatus involving new technologies has gradually come into the telephone plant. Its use has expanded at a slow rate. These various items have been scattered throughout Western manufacturing plants without any coordinated planning for them as a group. Engineers rotate through duty assignments to these jobs from large quantity production items that have little technical similarity where experience gained has little value for the highly technical, small production items of this group. This practice results frequently in work on a new and highly specialized job being carried out and immediately supervised by men with inadequate specific background and appreciation of the technology of the job." (Kelly, 1943, pp.10-11). Mowery (1983c) provides additional discussion of the implications of such "process-sensitivity" for the semiconductor industry.

10. Maclaurin (1949) quoted an interview with Frank Jewett, BTL director during the 1920s:

> Mr. Vail was not satisfied with the kind of service theparent company was getting from its laboratories in the Western Electric Company, and asked me to find out where the trouble lay. I soon discovered that the method that was being followed in rewarding engineers for their technical accomplishments was not satisfactory. The situation was an outgrowth of the conditions in the telephone industry in the 1880's and 1890's. This had been the 'era of the inventor' when it was vital to the future of the company to control the basic patents in the telephone art. In order to stimulate invention, the Western Electric Company had offered a reward of $100 for every patent issued. And this practice had continued into a period when the Bell Telephone System had become firmly established ahead of all rivals and the need for patents was no longer acute. The engineers would get together from time to time to discuss some new development, in which they were all interested. Each man would then go off by himself and try to develop the idea in secrecy to the point where a patent application could be made. Moreover, wherever it was possible to make a number of divisional patent claims, instead of one broad claim, this was done, even though a patent on one broad claim would usually be more valuable to the company. This method of remuneration was therefore abandoned and

any special rewards that were given thereafter were inthe form of a bonus for exceptional inventive accomplishment. (pp. 156-157).

11. "The sheer diversity of the overall AT&T system increased the likelihood of some benefits within the system resulting from any given scientific breakthrough. The wide range of economic functions provided by the integrated system, including both manufacturing and service functions, raised the likelihood that a new research finding in any one of the diverse areas within Bell Labs would yield an appropriable benefit somewhere within the larger integrated organization." (Rosenberg, 1982, p. 11)

12. The 1974 Touche, Ross study conducted for the Federal Communications Commission noted in Appendix 5 that "...the question of closer contact between the BTL system developers and the operating companies needs stressing. Over and over again in our perusal of documents on ESS [Electronic System Switching], as well as in interviews with BTL staff, we see the lack of direct or close connection between BTL and the operating companies serving as a significant barrier to the introduction of these systems." (p. 36). The reorganization of Systems Engineering in 1972 also points to some internal dissatisfaction with the quality of communications. This conclusion also needs to be tempered--while internal communications within the Bell System may have been less than ideal, this is not to say that these interactions would have been more productive in a non-integrated firm structure.

13. "Network evolution--the introduction of new technologies into the network--would also be unavoidably slowed [as a result of divestiture of the regional operating companies]. Today's network engineers strive to optimize the entire network in terms of size design, and configuration...Under the Government's divestiture scheme, however, optimization of the facilities of each firm, and suboptimization of the overall network, would become the fundamental principle of telecommunications engineering because network managers representing unaffiliated firms would understandably strive to optimize whatever part of the network belonged to and was the responsibility of their respective firms. And with retarded network evolution would come the near certainty of lowered productivity in the network as a whole." (Defendants' Third Statement of Contentions and Proof, pp. 2127-2128)

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R & D IN A POST-DIVESTITURE WORLD
Chair: Roger Noll

A. Michael Noll: The Impact of Divestiture on R&D In The Bell System

In 1981, Bell Labs spent $1.6 billion for R&D and employed 24,000 people. At the end of 1985, two years after divestiture, the combined spending for R&D at AT&T facilities and at Bellcore was $3.2 billion, and combined number of employees was 32,000. Clearly, in terms of spending and number of people, R&D fared quite well through divestiture. The predictions of dire consequences for Bell R&D have thus far not occurred.

A major effect of divestiture on R&D was the creation of a "new" facility, Bellcore, to satisfy the R&D needs of the newly-separated Bell operating companies. This diversification of R&D is continuing as some of the Regional Holding Companies (RHCs) start to create their own internal R&D activities to support their proprietary new business ventures. Clearly, this trend is linked to the easing of business restrictions on the RHCs.

This presentation will review the trends over time in R&D expenditures and personnel levels at AT&T and Bellcore. The recent excursions into R&D by some of the RHCs will be described. The presentation will end with comments on some of the future issues affecting R&D as a result of divestiture.

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THE IMPLICATIONS OF DIVESTITURE AND REGULATORY POLICIES FOR RESEARCH, DEVELOPMENT AND INNOVATION BY THE REGIONAL BELL HOLDING COMPANIES

by

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Telecommunications Policy Research
Airlie House, Virgina
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I. INTRODUCTION

In the three and a half years since the divestiture of its Bell operating companies by AT&T, there have been substantial changes in the organization of research and development in the restructured system. Although many of these changes have been positive, there are reasons to believe that the interaction of telecommunications markets and public policies may put the Bell operating companies at a comparative disadvantage, in the organization of R&D activities; in their incentives for R&D expenditures; in their ability to conduct productive R&D; and in the possibilities for their commercialization of successful R&D efforts.

In this paper, we will examine the changes wrought by divestiture (and major regulatory reforms) on the structure of the U.S. telecommunications markets and consider their probable impact on technological innovation in the industry. Of particular significance are the vertical disintegration of equipment manufacturing from the provision of telecommunications services; the vertical disintegration of local exchange services from interexchange services; the horizontal disintegration of local exchange service into seven independent Regional Holding Companies (RHCs); and the line-of-business restrictions imposed on the RHCs, which prohibit them from offering interLATA services, manufacturing telecommunications equipment or providing enhanced information services.

In assessing the impact of these changes in policy and industry structure, we realize that it is too soon to draw final conclusions from observed developments since the divestiture. By its very nature, innovation is a long-term proposition; the evidence available from the

short-run relates to the organization of, and expenditures on, research and development, which may be necessary, but is certainly not sufficient for successful innovation. We hope to avoid the common mistake of equating R&D with innovation:

> "The process of R&D has often been equated with innovation. If this were true, understanding innovation would be far simpler than it truly is, and the real problems would be far simpler and less interesting than they truly are. Successful innovation requires the coupling of the technical and the economic in ways that can be accommodated by the organization while also meeting market needs, and this implies close coupling and cooperation among many activities in the marketing, R&D, and production functions." [Kline and Rosenberg, 1986, pages 301-2]

While our principle concern is with U.S. telecommunications, it is undeniable that telecommunications equipment markets have been "globalized," in part due to the exigencies of technologies and market demand, in part to the liberalization of domestic policies in the U.S., Japan, Britain, France and elsewhere. So we will also consider the effects and implications of international competition in our assessment. In particular, we will emphasize the substantial differences between U.S. telecommunications policies and industry structure since divestiture on the one hand, and the structure of telecommunications services in other developed nations.

To anticipate those differences at the outset, note that only the U.S. has broken apart its formally integrated telecommunications system; in virtually all other countries - regardless of their regulatory policies on any other count - their remains a single, integrated provider of local, long distance and enhanced information services. Moreover, even where competition with the integrated carrier has been allowed (e.g., Britain and Japan), no substantive restrictions have been placed on the services offered by the integrated carrier.

In Section II, we briefly review the changes in the organization of and expenditures on R&D within AT&T and the Bell operating companies since divestiture. We weigh the effects of the division of the local operating system into seven independent companies on the role, mission and governance of their chief R&D facility, Bell Communications Research (BCR or Bellcore).

Having laid a descriptive foundation of R&D activities, we turn in subsequent sections to the effects of post-divestiture market structure and public policies on the probable success in innovation and its commercialization by the RHCs. In Section III, we explore the implications of the structure of telecommunications services markets for innovation. The salient issue there is the enormously greater need for, and difficulty of, developing standards for the Bell operating companies. We also consider the probable impacts of the growing competition among the RHCs for their willingness to collectively sponsor R&D activities.

In Section IV, we turn to the structure of telecommunications equipment markets, by considering the effects of global competition among equipment manufacturers, the development of strategic alliances among equipment manufacturers (for joint R&D, technology sharing and cross-marketing), and the vertical relations between the buyers and suppliers of telecommunications equipment.

Finally, in Section V, we examine the implications of three major policies for technological innovation by the RHCs: the line-of-business restrictions imposed by the Modification of Final Judgment; the FCC's Computer Inquiry III, especially the requirement for Open Network Architecture; and rate-of-return regulation of the Bell operating companies by state utility commissions.

The concluding section offers some general statements about the overall effects of divestiture on technological innovation in telecommunications. It is important to acknowledge that the body of the essay deals with the effects on the Regional Companies, which, in our view, are on balance negative. In is quite possible, though, that there have been offsetting benefits, i.e., positive effects on technological innovation by other firms in the industry.

II. THE STRUCTURE & ROLE OF R&D IN THE BELL OPERATING SYSTEM

By the divestiture of AT&T's local operating companies on January 1, 1984, the Modification of Final Judgment (MFJ) ended a century-long history of integrated telephone service in the United States. AT&T itself was drastically reduced in size: in revenues ($65 billion to $33 billion); assets ($148 billion to $39 billion); and net income ($7.3 billion to $1.4 billion). [Noll, 1987, page 163]. At the same time, seven new telecommunications entities were created, namely the Regional Holding Companies, which in turned owned one more of the Bell operating companies. A substantial part of Bell Labs, the research arm of AT&T, was split off into a new facility, Bell Communications Research, which is a wholly owned joint venture of the seven RHC'. In this section, we review the changes in the organization of research and development under the divestiture, and consider the effects of these changes on the mission and governance of Bellcore.

A. Organization of R&D at AT&T: Pre-Divestiture

There is no dispute that Bell Labs was (and is) an R&D institution of the highest caliber. Through its research prowess and productivity, Bell Labs and its scientists earned a reputation as perhaps the leading research

center in the world. Moreover, through its virtually guaranteed funding from Bell operating company "contract licenses," Bell Labs had the character of a public institution. As a matter of AT&T policy since the 1920's, and as a matter of law under the terms of the 1956 antitrust consent decree [HIGH TECHNOLOGY, June 1987], Bell Labs openly licensed its intellectual properties, including to its (now) competitors in telecommunications equipment and network services.[1]

Not only was AT&T required to openly license (and, by its own choice, publish) the results of Bell Labs' research, it was prevented from realizing the full benefits itself. Under the terms of 1956 antitrust consent decree, AT&T was prohibited from entering information processing - either manufacturing or services [HIGH TECHNOLOGY, June 1987, page 16].[2] Consequently, the "spillover" effects from Bell Labs were enormous, with U.S. and foreign firms in telecommunications, computers, semiconductors and consumer electronics among the beneficiaries. While often cited as a "national resource," Bell Labs was, in fact, a global resource.[3]

Two major reorganizations of R&D occurred at AT&T prior to divestiture. Under the terms of the FCC's Computer Inquiry II decision, AT&T was required to "structurally separate" its regulated services (interexchange services) from its nonregulated activities (equipment manufacturing, rental, maintenance and servicing) [Noll, 1987, page 91]. This separation also applied to AT&T's R&D. Hence, from 1982 to 1984, Bell

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[1] For an excellent historical review of Bell Labs, see Noll, 1987; see also Office of Technology Assessment, 1985.

[2] With one exception: its was allowed to produce equipment and provide services for its own internal needs.

[3] As of 1984, AT&T had 400 agreements outstanding in US, 200 with foreign firms. Office of Technology Assessment, 1985, page 113.

Labs shrank from 26,000 to 18,000 with roughly equal numbers going to AT&T Information Services (the newly created, nonregulated subsidiary) and the newly formed Central Services Organization (now Bellcore) [Wallich, 1985, page 91].

The second change, while complementary to the FCC-mandated split of Bell Labs, was an internal management decision, reflecting concern with Bell Labs' product development capabilities.[4] In order to more fully integrate Bell Labs researchers and development specialists into the operations of the Company, R&D was reorganized along lines of business, with authority for managing design and development shifted to the head of each respective business division [Office of Technology Assessment, 1985, page 122].

At the breakup, 3500 additional people were transferred to Bellcore to provide research and engineering support for local operating companies. The people transferred included research and engineering staff whose work supported local switching and network systems as well as a "cross section of researchers from Bell Labs." [HIGH TECHNOLOGY, June 1987, page, 91]

B. Organization of R&D at AT&T: Post-Divestiture

During the antitrust trial, and in reaction to the announcement of the proposed consent decree, there were dire predictions that the divestiture would have devastating effects on Bell Labs.[5] The early

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[4] While Bell Labs prowess in basic research was widely touted, it was growing criticism regarding its failure in exploiting the full potential its research results at the product development and commercialization stages.

[5] Those predictions were founded on two premises: (1) the loss of contract license fees from local operating companies would deprive Bell Labs of the secure revenues needed to support pure research; and (2) the vertical disintegration of local services which would limit AT&T's ability to "appropriate" the benefits

evidence does not seem to support those predictions: in terms of patents, publications, employment, budget, and research climate and composition, there has been no dramatic changes, perhaps even some improvements at Bell Labs since the divestiture [Noll, 1987, page 165-170].[6]

Indeed, even though AT&T was greatly reduced in size, R&D expenditures have increased by 60% since divestiture, leading Noll to speculate (on the basis of R&D expenditures of comparable firms) that AT&T may even be "overinvesting" in R&D [Noll, 1987, page 173]. The Labs' research budget is now 7.5% of AT&T's $3 billion total R&D budget, compared to 10% of Bell Labs' $2 billion overall budget before divestiture [HIGH TECHNOLOGY, June 1987, page 17].

While observers may well disagree on whether AT&T is now spending too little or too much on R&D, there is little disagreement that the fundamental purpose of R&D has changed dramatically:

> "AT&T's purpose in research and development is to turn ideas into products that it can build and sell...When Bell Labs and Bellcore went their separate ways, they also took on new charters to replace the old Bell Labs charter of providing the technology base for the phone system... Now half a dozen companies may be involved in selling the equipment and services for a single connection. Bell Labs and Bellcore may both continue to consider the problems of providing end-to-end connections, but no one can mandate a unified solution... This

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of innovation through ownership of "co-specialized assets," namely central offices and local loops. For a discussion of appropriability and the role of co-specialized assets in innovation and commercialization, see Teece, 1986.

[6] In his interviews, Bellcore managers and researchers did express concern about effects of AT&T's financial difficulties in new business ventures, and effects of competition in traditional businesses. Noll, 1987, page 170. There is also evidence of a substantial increase in the rate of turnover among Labs employees, but even then, the current turnover rate is comparable to that experienced by other large R&D facilities. HIGH TECHNOLOGY, June 1987, page 19.

change limits the charters of the two main successors to Bell Laboratories: no longer can they be responsible for "the big picture" of telephone communications." [Wallich, 1985, pages 91-3].

There is the additional concern over the "privatization" of knowledge and research results. AT&T is required, under the MFJ, to issue licenses to the RHCs on all existing patents, plus nonpatentable technical information funded by license contracts. On new patents, however, the MFJ licensing requirement covers only five years after the date of divestiture [Office of Technology Assessment, 1985, page 121]. Moreover, while AT&T continues to license many of its patents to non-RHCs, it is no longer required to do so (MFJ lifted that requirement of the 1956 Consent Decree). AT&T has publicly announced that it now regards patents as assets, evaluates each licensing requests on its merits and grants licenses only when it finds a business advantage in doing so [HIGH TECHNOLOGY, June 1987, page 19].

But AT&T's strategic approach to R&D should hardly be surprising. For at least three reasons, we would expect a high level of R&D expenditures after the breakup. First, AT&T has a window of opportunity during which it could get a "leg up" on competitors. Given the line-of-business restrictions on RHCs, and AT&T's well established position in the switch market (enormous embedded base, large share of new shipments), an intensive R&D effort is crucial to sustaining its competitive advantage as foreign manufacturers enter the market and after (assuming that) the RHCs are allowed into enhanced information and/or long distance services.

Second, so long as revenues from regulated services constitute a large share of its total revenues, AT&T can include a substantial share of its R&D expenditures in "allowed expenses" for long-distance ratemaking purposes. Under the FCC's, "composite allocator" rule, 50% of AT&T's R&D

costs are paid by regulated AT&T Communications, 50% by nonregulated AT&T Technologies and AT&T Information Services [Office of Technology Assessment, 1985, page 129].[7]

Third, AT&T is losing share in long distance, and rental revenues will continue downward. Looking into the future, AT&T needs new sources of revenues to maintain its long-term growth trajectory. Especially with long-distance customers paying a share of the costs,[8] AT&T has an opportunity to harness the labs in an effort to develop the new products and services of the future.

Sooner or later, though, competitive pressures may force AT&T to devote a larger share of R&D to product development, less to long term research [Office of Technology Assessment, 1985, page 113]. In a sense, AT&T is subsidizing national and global science, through its liberal publications and licensing policies. The question is how long that can continue, in the face of increasing competition in all of its markets. We can only hope that AT&T managers resist these pressures, since a drastic reduction in Bell Labs research efforts would represent the loss of national asset of great consequence to U.S. technological leadership in communications, information and related industries.

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[7] AT&T revenues in 1985 by LOB: $17B in regulated services (toll, installation, maintenance); $11B equipment sales; $6 rentals; Globerman and Diodati, 1980, page 173. Hence, 50% of R&D goes into allowed operating expenses for long-distance rates. Under rate of return regulation, the incentive to spend on R&D is especially strong when revenues are producing profits in excess of the allowed rate of return, as has in fact been the case for AT&T.

[8] We are not suggesting, nor do we believe, that the cost allocation of R&D expenses to AT&T Communications is inappropriate; the users of interexchange services may well be receiving at least a proportional share of the benefits.

C. Organization of R&D among the Regional Bell Holding Companies

Since divestiture, virtually all organized research and development activities of the RHCs takes place at Bell Communication Research, which is wholly owned by the seven Regional Holding Companies.[9] As of 1986, Bellcore had 8000 employees: 4600 of whom worked in Technical Services: 500 in applied research and 4100 in network planning, software development, quality assurance and new service planning. Bellcore projects are of two basic kinds: core projects are conducted on behalf of, and funded by, all seven RHCs; client projects are conducted for, and funded by one or more RHCs, each of whom must individually agree to participate as sponsor [Globerman and Diodati, 1980, pages 70-85]. Of Bellcore's total budget, one-third is spent on core projects, two-thirds on client projects [BCR Annual Report, 1986]. Whereas core projects provide results to all seven RHCs, client project results are shared only with project sponsors.

As a research cooperative, Bellcore has experienced the problems inherent in collective decision-making over which projects to fund and for how much. US West in particular has expressed concern about BCR governance and the need for consensus among the owners in the funding decision process [Roberts, 1987a, page 5]. In January 1987, US West notified Bellcore of its intent to sell its share of stock, effective January 1, 1990.[10] US West was

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[9] According to Noll, 1987, and my own review of RHC Annual Reports, any R&D expenditures other than payments to Bellcore are *de minimis*.

[10] This does not mean that US West intends to actually quit Bellcore; their letter is a formal compliance with the three-year notification requirement to preserve their flexibility three years hence.

> "reportedly protesting Bellcore's governance by consensus process while stating its need for Bellcore to conduct more proprietary research. Its action could be seen as an attempt to spur changes in Bellcore's governance procedures... [It] believes that as the RHCs compete with each other, Bellcore should handle more special or region-specific projects, and fewer core projects" [TELEPHONY, January 19, 1987, page 13].

While it has a substantial budget (approximately $800 million) Bellcore's scope limits activities since only about 500 employees are working in applied research.[11] According to a Bellcore Assistant Vice President,

> ...Bellcore can't match its predecessor's [Bell Labs] scope. Instead, he contended, the best thing for Bellcore to do is to focus its research on areas where small groups of people can have a real impact and where the company has special expertise inherited from the old Bell System. [Wallich, 1985, page 94].

In an effort to contend with this limitation in scope, Bellcore is a participant in The Microelectronics and Computer Technology Corporation and is engaged in collaborative research with the U.S. Army Electronics-Technology and Devices Laboratory, ADC Telecommunications, Inc. and Hitachi, Ltd. [Bell Communications Research, 1987, page 2].

US West's notification letter notwithstanding, most reports of RHC relations with Bellcore are quite positive. The three RHCs interviewed by Noll were very enthusiastic about Bellcore, even though there are conflicts because RHC non-regulated businesses (e.g., cellular phone service, overseas engineering services) are sometimes competitive [Globerman and Diodati, 1980, page 176]. According to a Pacific Bell executive,

> "We treat Bellcore as a vendor with a client relationship... It is a matter of establishing a pro-active attitude with them. We see Bellcore as an extension of our staff - a value-added service.'" [DATA COMMUNICATIONS, page 79]

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[11] By Comparison, Siemens' new R&D lab in Boca Raton, Florida, also employs 500 researchers; the lab is dedicated to CO switch development.

Even so, recent actions by Pacific Bell and others feed rumors that the RHCs will be increasingly "going it alone." In their design and testing of Project Victoria (a prototypical integrated services technology), Pacific Bell conducted the requisite research in house. Likewise, Pacific Bell has opted to develop and use their own system, rather than fund Bellcore's Trunk Integrated Records Keeping System (TIRKS), which cost each of the other six RBOCs $10 million in 1985 [DATA COMMUNICATIONS, 1986, page 79].

Even so, Pacific Bell claims it is not pulling out of Bellcore: Thomas Edrington, PacBell's Assistant Vice President of Technology has stated his company's position in these terms:

> "We receive top quality technical talent and research results for, in essence, one-seventh of the dollar. The challenge is to be able to continue our very good working relationship with Bellcore... While we do a limited amount of research ourselves, our approach is to have highly qualified individuals who can integrate their abilities with other outside resources, Bellcore being the primary one." [PACIFIC BELL UPDATE, April 6, 1987]

One argument for developing greater in-house R&D capacity is that the RHCs need their own research capability, if only to measure, monitor, and decide whether to fund Bellcore activities. A second argument is that, as the RHCs compete in more markets and attempt to differentiate their services from each other, their need for proprietary research and research know-how will increase. We examine that possibility in Section III.

D. Mission of Bellcore R&D

In response to the MFJ's vertical disintegration of Western Electric from the operating companies and in light of MFJ's ban on RHC manufacturing, Bellcore's central mission was rather obvious: to provide technical support of the RHCs equipment buying decisions:

> "[Bellcore's] mission is to provide technological support to the local operating companies so that... they can make the best decisions on what equipment to install to serve their customers. Good decisions require knowing as much as possible about about the interactions between telephone handsets and other customer premises equipment, local lines, switching centers, long-distance lines, and so forth - much like the work of the old Bell Labs." [Wallich, 1985, page 92]

A key aspect of that mission is, of course, to develop standards for multiple vendors, to ensure compatibility within and across local operating systems. We examine that subject in greater depth in Section III; suffice it here to note that, in providing procurement-related technical support to the RHCs, BCR needs to keep ahead of - not merely up with - equipment manufacturers, anticipating state-of-art developments by doing its own research. This research capacity and knowledge base is essential to Bellcore's ability to specify, evaluate and test products for the RHCs [Office of Technology Assessment, 1985, page 129].

Given the increasing competition in the provision of local network services (e.g., private networks, carrier bypass), the RHCs also have an important stake in promoting innovation by the manufacturers of central office switches and local network systems and software. Another Bellcore mission, accordingly, is "to keep abreast of new ideas, so it can advise its owners-the operating companies-about what to buy and disseminate any discoveries that it makes to manufacturers of communications equipment - including AT&T." [Wallich, 1985, page 93].

This explains Bellcore's patents and licensing policies. While Bellcore does seek patent protection for intellectual properties,[12] "Bellcore wants to encourage vendors to share the fruits of Bellcore's

[12] Bellcore patents are increasingly rapidly, with 15 patents issued, 5 allowed, 75 pending, and 50 more applications expected in 1987, according to Bellcore's President. Marano, 1987, page 87.

inventions, and this has led to a fairly open publication and licensing policy." [Globerman and Diodati, 1980, page 175] This interest in disseminating knowledge derived from research, design and testing activities is also reflected in the publishing records of Bellcore employees. [Noll, 1987]

Of course the main reason why Bellcore openly publishes and licenses is the line-of-business restrictions on the RHCs, which also apply to Bellcore. Since Bellcore and the RHCs are prohibited from developing or manufacturing telecommunications equipment themselves, Bellcore can only specify the criteria or design standards outside vendors' equipment should meet. Furthermore, Bellcore can only make recommendations on design specifications or standards to the RHCs, who are free to accept or reject them. Any effort to impose mandatory standards would surely be challenged on antitrust grounds [Wallich, 1985, page 92].

In that context, Bellcore faces a difficult technical problem in defining the boundaries of the line-of-business restriction on manufacturing. Under the MFJ, software development is allowed, while equipment development and manufacturing are not. It is increasingly difficult to make that distinction, however, as technological change complicates the differentiation of R&D into equipment- or software-related, because hardware is rapidly becoming more software intensive [Markey and Blau, 1986, page 5].

E. RHC & Bellcore R&D Expenditures

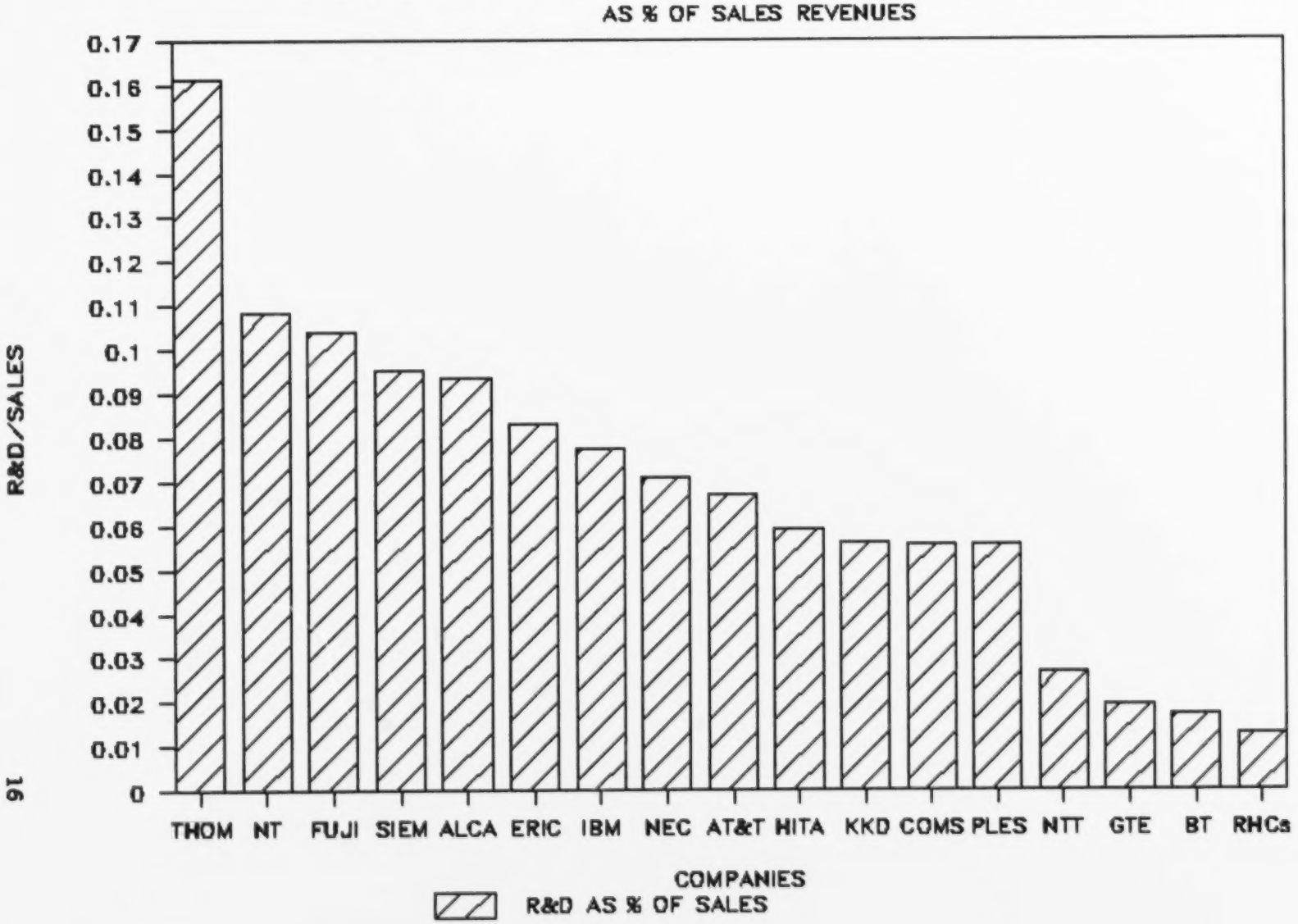
Although Bellcore's budget is a very substantial $800 million per year, when measured as a percentage of the revenues (1.3%) of its owners, these expenditures are markedly lower than other telecommunications companies or other high technology industries. As shown in Table 1, total

Table 1: 1986 R&D Expenditures in Communications and Information Equipment and Services

COMPANY/INDUSTRY	1986 SALES REVENUES	1986 R&D EXPENSES	R&D AS % OF SALES
TELECOM SERVICES:			
RHCs/BELLCORE	$62,502	$803	1.3%
BRITISH TELECOM	$12,581	$216	1.7%
COMSAT	$466	$26	5.6%
KKD	$1,200	$67	5.6%
NTT	$28,286	$757	2.7%
SERVICES/EQUIPMENT:			
AT&T	$34,087	$2,278	6.7%
GTE	$15,112	$291	1.9%
IBM/ROLM/MCI	$51,250	$3,975	7.8%
TELECOM EQUIPMENT:			
CIT-ALCATEL	$10,700	$1,000	9.3%
ERICSSON	$2,779	$231	8.3%
FUJITSU	$7,942	$826	10.4%
HITACHI	$27,836	$1,644	5.9%
NEC	$12,970	$917	7.1%
NORTHERN TELECOM	$4,384	$475	10.8%
PLESSY	$2,192	$122	5.6%
SIEMENS	$34,600	$3,300	9.5%
THOMSON-CSF	$22,300	$3,600	16.1%
RELATED INDUSTRIES:			
COMPUTERS	$94,138	$7,857	8.3%
ELECTRONICS	$59,311	$2,586	4.4%
OFFICE EQUIP	$5,147	$249	4.8%
PERIPHERALS	$23,021	$1,615	7.0%
SOFTWARE	$6,086	$468	7.7%
TELECOM EQUIP	$54,502	$2,762	5.1%
ALL INDUSTRY COMPOSITE, U.S.	$1,451,000	$51,000	3.5%

Sources: Corporate Annual Reports; Japan Company Handbook; BUSINESS WEEK, "R&D Scoreboard," June 22, 1987, pp. 139-158.

FIGURE 1: 1986 R&D EXPENDITURES



RHC R&D expenditures are only 20% of AT&T's expenditures when measured as a percent of sales.[13] While telecommunications firms average R&D expenditures nearly equal to pre-tax profits (94%), the RHCs spend only 5% of pre-tax profits on R&D. By comparison to software services firms,[14] the RHCs spend only one-sixth as much on R&D (1.3% of sales versus 7.7%).

In Table 1 and accompanying Figure 1, Bellcore's expenditures are compared to the RHCs actual and potential competitors. With no exceptions, the RHCs spend far less on research and development. Of particular significance are the R&D expenditures of British Telecom and Nippon Telecom, both of which are primarily telecommunications services firms with limited involvement in (but no restrictions on) telecommunications equipment manufacturing. Whereas the Bell companies collectively spend 1.3% of sales and 5% of pre-tax profits, British Telecom spends 1.7% of sales and 8% of profits, while NTT spends 3% and 36%, respectively.

We think these comparisons reflect the peculiar circumstances of the RHCs since divestiture. Unlike the Bell operating companies, and not withstanding privatization and deregulation, neither British Telecom nor NTT were dismembered horizontally nor vertically. Each provides nationally extensive local exchange and interexchange telecommunications services;[15] neither faces significant restrictions on the provision of enhanced

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[13] As already noted, virtually all RHC expenditures on R&D are payments to Bellcore, whereas Bell Labs' budget represents only a part of AT&T expenditures on R&D.

[14] Since the RHCs are allowed to research and develop their own software, this is particularly revealing comparison.

[15] It is particularly worth noting that both Japan and Britain have opened exchange and interexchange services to competition (Japan has three new long distance carriers, Britain one), but did not see the necessity of separating local from long-distance carriers in order to do so.

information services; and while neither has historically been integrated into manufacturing, both have "quasi-integrated" relationships - including joint R&D ventures - with domestic telecommunications equipment manufacturers [Teece, Pisano and Russo, 1987, pages 17-8]. In the subsequent sections, we will probe the implications of market structure and public policies of U.S. telecommunications for research, development and innovation by and among the RHCs.

III. THE EFFECTS OF EXCHANGE SERVICES MARKET STRUCTURE

The most obvious effect of the divestiture of the Bell operating system was the creation of seven independent holding companies, each providing local and intraLATA toll service to roughly one-ninth of the U.S. population.[16] This makes the U.S. the only developed nation with an interconnected system of regional operating companies providing local service; all others have a single company providing the whole nation with local and long-distance service, whether or not there are competitors to it. In this section, we discuss the implications of the horizontal disintegration of the Bell operating system on R&D and innovation by the RHCs.

A. Standardization and Compatibility in Exchange Services

The horizontal disintegration of the local telephone network greatly increases the need for standards, and the potential for incompatibility. Farrell and Saloner have categorized a number of mechanisms for

[16] The remainder of the population is served by General Telephone or one of the many other independents, so even before divestiture, we were the only developed nation in the world without a single, fully integrated telecommunications services provider.

standardization, which they define as "a *process* by which compatibility is attained" [Farrell and Saloner, 1987, page 3]:

> (1) an internal decision by one vendor (e.g., AT&T prior to divestiture);
>
> (2) mutual agreement among vendors or purchasers; formal or informal, binding or voluntary (e.g., Bellcore since divestiture);
>
> (3) use of government procurement (e.g., PTTs in Europe);
>
> (4) follow-the-leader (e.g., UNIX or "IBM-compatible");
>
> (5) direct government regulation (the FCC's Open Network Architecture requirement, perhaps); and
>
> (6) international standards setting (the International Telecommunications Union's ISDN standards).

The significance of the divestiture is that the first mechanism of standardization is no longer possible in the U.S., while the third never was. The fourth is unlikely, since no single vendor sufficiently dominates any substantial sphere of telecommunications equipment. The fifth is highly improbable, at least across all telecommunications products and services."[17] The sixth mechanism, international standard setting is frought with the political contestations of fiercely nationalistic PTT's (which, it should be emphasized, do not need international standards for their domestic networks, since they can depend on the third mechanism).

That basically leaves the second mechanism, voluntary standard-setting by Bellcore (or equipment vendors),[18] and accounts for Bellcore's "technology clearinghouse role." Even then,

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[17] As already noted, even an attempt at mandatory standardization by Bellcore would surely be tested by a "losing" vendor under the antitrust laws. Moreover, Judge Greene implicitly relied on such a standard in denying the recommendations of the Department of Justice to remove MFJ restrictions on RHC manufacturing.

[18] Katz has remarked that

> "some outsiders...worried that this common clearinghouse of standards and technology would allow the same kind of anticompetitive collaboration that the breakup was supposed to end. As it becomes clear that the seven Baby Bells are taking their independence seriously, those fears are easing. In fact, with Bellcore's owners going off in seven different directions, the organization's role in keeping local phone service healthy may be needed more than ever." [BUSINESS WEEK, December 2, 1985, page 106]

Given the ever-present shadow of antitrust enforcement and monitoring of the MFJ provisions, BCR must establish reasonable standards to ensure the highest possible level of compatibility while not skewing those standards so that they favor any particular equipment supplier. Bellcore is sensitizing its employees to the antitrust implications of standard setting by internal training. Claims Bellcore President Marano: "We are not going to set standards unilaterally." [McClenahen, 1984, page 31] As part of its efforts to avoid claims of anticompetitive conduct, Bellcore works within the American National Standards Institute as part of an industry-wide effort to establish and maintain telecommunications network connection standards [McClenahen, 1984, page 32].

In spite of its antitrust concerns and strict adherence to voluntary standards and design specifications, Bellcore has been actively sought to develop standards for generic operating systems, network elements and the

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> "The prevailing view among industry and government economists and engineers appears to be that, if there is a distortion, it is that the private incentives to achieve standardization are too low...[H]owever, the theoretical work in this area does not support the view that private incentives will unambiguously be too low from a social perspective. The divergence between the social and private standardization incentives may be either positive or negative." Katz, 1986, page 3.

If this view is correct, we should be more sanguine about the prospects for telecommunications standardization. On the basis of current evidence, though, we are not so hopeful.

interfaces among them. In pursuit of these objectives, Bellcore has issued Technical Advisories and Technical References; conducted "Technology Requirements Industry Forums;" and participated in the Exchange Carriers Standards Association's T-1 Committee [Rutkowski, 1987b, page 44].

Clearly Bellcore and the RHCs recognize the importance of compatibility across and among the local operating companies, including the independents. The benefits of compatibility include:

> externalities (as the size of a compatible network increases, the value of service to each user increases);
>
> competitive effects (when competitors' products are compatible there is typically greater price competition among them);
>
> cost savings (from scale economies in the use of standardized and/or interchangeable parts); and
>
> greater variety in systems design (the ability to mix and match various components and sub-systems) [Farrell and Saloner, 1987, pages 6-8].

Considerable benefits notwithstanding, the problems in maintaining compatibility are not insignificant.[19] In the absence of Bellcore, these problems of coordination and communication among the seven RHCs would be considerable.[20] There is the additional problem of the RHCs' large installed base of Western Electric equipment, which complicates the movement toward a new, generic standard [Farrell and Saloner, 1987, pages 15-18].

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[19] It must be remembered that the extraordinary level of compatibility we have in telecommunications is the inheritance of an integrated network. The question is whether disintegration will cause a reduction in compatibility in the future.

[20] In the colorful language of Farrell and Saloner, Bellcore is the rope tying the RHCs together, keeping them from wandering too far from the cowboys' campfire during the night.

Of particular concern in the area of standardization is the role of Bellcore acting on behalf of the RHCs in international standards setting activities.[21] As already noted, the PTTs are structurally dissimilar from the RHCs: they each have an extensive, integrated national network offering local, long-distance and enhanced information services and they are quasi-integrated telecommunications with one or more favored national suppliers. Surely their interests are markedly different from the RHCs; they have an abiding interest in pushing standards in the direction of network integration, while the RHCs are, of legal and regulatory necessity being pushed in the direction of open network configurations.

Furthermore, one should not underestimate the role of the PTTs and their respective governments in the international standard setting process:

> "By virtue of the leverage they are recognized to possess within the domestic arena, and the potential influence they may exert over the terms of international competition through advocacy of particular standards, it is thus to be expected that individual government agencies will become entangled thoroughly in dynamic market rivalries between sponsored-system standards." [David, 1986, pages 47-49]

In comparing Bellcore's R&D expenditures to other telecommunications firms, it should be noted a substantial share of these expenditures are devoted to ensuring continuing compatibility through standardization.[22] While potential social harm is prevented thereby, this hardly represents an improvement on pre-divestiture conditions. With vertical integration between Western Electric and the Bell operating companies, Bell Labs could

[21] The RHCs involvement in international standard setting is coordinated by Bellcore's Network Standards & Architecture Client Program Bell Communications Research, 1987, pages 3ff.

[22] We are certainly not suggesting that Bellcore's specification, standardization and testing activities do not generate innovative results; they surely do. We are saying that divestiture has imposed an enormous cost that was unnecessary in an integrated AT&T.

concentrate on designing and developing hardware and software, rather than on specifying standards for outside vendors. As we will see in subsequent sub-sections, the cost of standardization imposed by divestiture is likely to grow as time passes.

B. Cooperation Among Competitors

Given the divestiture, and quite apart from the need for standardization among the RHCs, there are considerable benefits of cooperative research, both private and social. The social benefits of cooperative research, as classified by Grossman and Shapiro, include:

> *ex ante incentives to invest in R&D*: cooperation among competitors may solve appropriability problems (i.e. leakage of the results of R&D, lowering the returns to R&D expenditures);
>
> *economies of joint research*: including economies of scale, synergies or complementarities among participants, avoiding duplication, and risk sharing;
>
> *ex poste dissemination*: cooperatives treat knowledge as public good, at least among members, which guarantees diffusion of the results of R&D and thereby increases the return on R&D; in fact, a "cooperative research effort may be viewed as an *ex ante* licensing agreement with zero licensing fees" 32123].

There are potential social costs of cooperative research as well. These include the loss of dynamic efficiency in R&D (when firms use cooperative research ventures to slow pace of technological innovation, thereby protecting physical assets, human capital and/or market positions); and anticompetitive dangers in product markets, ancillary restraints are attached to cooperative R&D ventures [Grossman and Shapiro, 1986, pages 324-25]. As a rule, the net incentives for, and social benefits of, cooperation are positive when participating firms sell their outputs in unrelated product markets, as do the RHCs [Katz, 1986, 529].

Nelson [1986, page 30] has explained the advantages of sharing R&D results among rivals in these terms:

> "Rivalrous firms may also forge agreement to get done cooperatively certain kinds of research where the results are difficult to keep proprietary, or where it would be disadvantageous to the whole group to do so...In many instances an industry can collectively benefit by devising and generally accepting certain uniform practices, or standards, particularly for the products of upstream industries. There is a tradition in many industries to fund this type of work collectively, through some kind of voluntary tax formula... There are obvious free rider limits on this mechanism, however. And there are technology transfer problems." [Nelson, 1986, page 30][23]

In considering the incentives for and benefits of cooperative research by the RHCs, we note that BCR prevents free riding among its member-owners for core projects, but independents, who may well buy the same equipment, do free ride. Also note that in the typical case of cooperative research, members use the results directly, in the production and sale of goods or services. In the RHCs' case, given the line-of-business restrictions, Bellcore must either license, or give away its results to supplying firms. We will expand on this point in Section IV.

C. Competition Among Cooperators

As already noted, Katz has shown that the private incentives for cooperative R&D are positive when firms sell their products in unrelated markets. In other words, firms are more likely to cooperate when they don't compete. At the time of divestiture, of course, the RHCs fit that bill completely. They had very strong mutual interests in quickly developing a collective research, development, standardization and testing capability, the cost of which could then be spread over the seven owners.

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[23] Nelson has cited The Microelectronics and Computer Technology Corporation as an example of the potential benefits of cooperative generic research: "...by treating generic knowledge as a public good for the group, and by financing it as such, the involved firms are gaining efficiency advantages." Nelson, 1986, page 30.

In the years since divestiture, however, the RHCs have increasingly become (especially in nonregulated lines-of-business such as telephone equipment marketing and cellular phone service), and perceive themselves as, competitors. There are already signs of the tensions of emerging competition in the governance of Bellcore, in the RHCs relations with Bellcore, and in the establishment of internal R&D groups at the RHCs.[24]

Although wholly owned by the seven RHCs, and even with fairly close and cordial relations between Bellcore and its owner-members, the fact remains that Bellcore is an "outsider" in one critical respect. Hence, it seems probable that

> "As the regionals branch out in new directions, and even compete head-to-head in some markets, they will want to keep some information and technology private. The lab may be cut out of top-priority projects - the regionals aren't likely to leave the development of key, competitive technology to outsiders." [BUSINESS WEEK, December 2, 1985, page 106]

We expect two main effects of growing competition among the RHCs on the organization and conduct of R&D. First, Bellcore will shift its efforts from core projects shared by all seven RHCs to proprietary, client-oriented research and development. US West has already argued that BCR research should reflect growing rivalry among RHCs, by undertaking more proprietary research [Roberts, 1987a, page 5]. Bellcore has recognized the handwriting on the wall, declaring that more work regional specific "will be committed, executed and delivered to satisfy separate regional Bells."

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[24] Even prior to these developments, this eventuality was recognized by astute observers:

> "It is possible that the growing competition between the owners could encourage them to jointly fund basic research at Bellcore, but turn to other labs [including internal] for development of products needed for the competitive market." Office of Technology Assessment, 1985, page 130.

[Roberts, 1987b, page 6] Over time, Bellcore will increasingly become a contract research lab, which will have to compete with the RHCs' internal labs, private concerns, and universities for R&D projects. As it does, BCR might want to take on other customers, but the MFJ currently prohibits it from serving the broader market [Roberts, 1987b, page 6].

The second effect of growing RHC competition is the establishment of internal R&D groups by the RHCs.[25] In recent months, SW Bell and US West have announced creation of their own R&D groups to generate needed proprietary research to support new, competitive business ventures (cautioning that they don't intend the internal groups to replace Bellcore) [Scott, 1987]. NYNEX has announced plans for an R&D organization of 350 by 1990, including a small applied research group of 35; mostly software related. Pacific Bell has a small technology tracking group, but has no plans for its own R&D facility. US West has also announced plans for a R&D facility, causing something of a ruckus over its site selection process [Noll, 1987, page 177]. In addition, US West recently announced $1.2 million in university grants "for R&D on 10 key technologies deemed crucial in its competitive marketplace." [TELECOM TACTICS & STRATEGIES, 1987, page 1].

The sum of these two effects, an increasing share of RHC research done internally and an increasing share of proprietary research at Bellcore, may well reduce the public benefits of research and development expenditures by the RHCs. In other words, growing competition among the

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[25] Over time, we expect to see more of the second response than the first. While an RHC can attempt to protect disclosure of the results of proprietary research from other RHCs, such contracting is notoriously difficult. Moreover, in contracting with any outside R&D facility for proprietary work, the RHC loses most of one of the most valuable outputs of R&D, "learning by doing." Teece, forthcoming.

RHCs will shift the balance from the social benefits of widespread diffusion to the incentives of privatization.

D. Competition Between Exchange, Interexchange Carriers

Under the MFJ, BOCs are not allowed to provide interLATA services, while interexchange carriers - including AT&T - are allowed to provide intraLATA service, depending only on state regulatory approval. In most states, IECs are authorized to offer private line services; some states have authorized open entry into the LATAs. The emergence of competition between IECs and the BOCs has two main implications for innovation.

First, there is a technological consequence: "Local system/central office architectures and network architectures are becoming decidedly blurred at the boundaries." [Rutkowski 1987b, page 46] Again noting the difference between the U.S. and other national telecommunications systems, though, it seems unlikely that world telecommunications markets will follow the same trajectory. With other carriers - the PTTs - having integrated networks, innovations developed for the U.S. market will have limited applicability elsewhere. The return on U.S. R&D will be correspondingly lower.

A second consequence of the vertical disintegration of local from interexchange services derives from AT&T's unique position as a supplier of, and competitor to, the RHCs. AT&T sells PBXs to corporate customers and Centrex switches and software to the BOCs;

it sells interoffice transmission equipment to BOCs and private line services to the BOCs potential customers. Moreover, the greatest potential arena of competitive rivalry lies just ahead, as AT&T develops the modifications and software needed to provide local switching and enhanced information services from its Class 4 switches, in direct competition with

the BOCs' Class 5 central office switches. Already there are claims that AT&T is holding back software development on its 5ESS switches (which, due to pre-divestiture standard practice procurement policy, constitute a large share of the BOCs' installed base of stored program control switches).[26] AT&T, meanwhile, is reported to be rapidly developing the Class 4 switch for a central role in ISDN [Markey and Blau, 1986, page 4].

IV. THE EFFECTS OF THE VERTICAL STRUCTURE OF EQUIPMENT & SERVICES

In this section, we briefly describe the structure of telecommunications equipment markets, emphasizing the manufacture of central office switches (COs). While other categories of telecommunications equipment (e.g., optical fiber and transmission equipment, PBXs) are also undergoing rapid technological development, it is evident that the design and development of switches will play a crucial role in the technological trajectory of the industry.[27] The BOCs view

[26] AT&T's 4ESS toll switch and 5ESS local/toll switch both provide digital stored program control, but AT&T's best chance in the switch market lies with the 5ESS, because

> "...[it] combines class 5 local and class 4 toll capabilities [and] its modular design allows for new hardware components, new software controls, and new customer features. Thus, it should not become obsolete for another 15-20 years."

Kellagher, 1987, page 78.

[27] By this characterization we mean not just the switch *per se*, but switching systems and network architecture. This is an especially critical period for R&D because

> "...the introduction of high-speed packet and burst switching in the early 1990's promises to so dramatically change the entire integrated information transport fabric, from the microscopic to the macroscopic, that although system engineers and network planners are developing migration plans, the ultimate consequences are only beginning to become apparent."

enhanced digital COs as critical for several reasons: (1) they facilitate easy conversion to MFJ-required equal access; (2) they are essential for the development of wideband networks that transmit voice and data simultaneously; and (3) they provide software-driven enhanced information services.[28] Advancements in COs are essential to the BOCs' hopes for a central position in ISDN [Rutkowski, 1987b, page 68].

The divestiture separated the Bell operating companies from Western Electric, the source of 90% or more of their equipment prior to divestiture. In this section, we evaluate the effects of the vertical disintegration of the Bell system on R&D and innovation by the RHCs. We begin with a brief review of the market structure of central office switches, taking special interest in the installed base the market shares of North American (AT&T and Northern Telecom) versus European and Japanese manufacturers in the U.S. market.

We then investigate R&D in the telecommunications equipment industry, with special attention to the recent dramatic increases in collaborative R&D efforts, including joint ventures in (or including) R&D or technology sharing arrangement. We describe the emergence of "global strategic partnerships" among equipment manufacturers and PTTs (and former PTTs) of

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Rutkowski, 1987b, page 50.

[28] According to Kellagher,

> "These enhanced services are the key to making the telcos competitive in their fight to prevent bypass of the local loop and prevent loss of large customers and revenues to private networks. Telcos are now emphasizing services their customers request at the best price. These services depend upon a digital network, because simultaneous, high-speed voice/data transmission offers the best technology as well as the lowest cost."

Kellagher, 1987, pages 74, 76.

Western Europe and Japan (e.g., IBM's joint venture with NTT of Japan; AT&T alliances with Olivetti and Philips). We will explain the notable absence of the RHCs from these strategic partnerships and its implications for RHC participation in technological innovation.

Finally, and most importantly, we describe and analyze the vertical relations between the RHCs and telecommunications equipment manufacturers. Specifically, we view this relationship as an example of "upstream-downstream R&D cooperation," and derive its implications for RHCs' incentives for R&D and the appropriability of innovations produced thereby.

A. Structure of Telecommunications Equipment Markets

While vertically integrated with Western Electric, the BOCs purchased more than 90% of their equipment internally. Western Electric supplied all of the BOCs' CO needs until 1980, when the Bell System approved Northern Telecom as a CO supplier.[29]

As of 1986, the BOCs had an installed base of 9351 switches, the majority of which were made by AT&T, with Northern Telecom in distant second. Approximately 50% of their COs were analog electronic, 32% analog with stored program control, and 18% digital (nearly double the number of 1985 [Kellagher, 1987, page 76].

Overall, the U.S. CO market (including BOCs, GTE, independents, REA Coops and private network purchasers) is dominated by three vendors: AT&T, 45% of 1985, 86 digital lines shipped; Northern Telecom, 38%; GTE 13%; and all others 4%. CO shipments increased 10% to 16.2 million in 1986 (14.7 mil in 1985). By share of lines, 90% of 1986 shipments were digital CO, the

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[29] Northern Telecom's small DMS-10 digital switch was approved in 1980; its larger DMS-200 toll switch was approved in 1982. Kellagher, 1987, page 76.

remaining 10% were components for expansion or modification of existing analog systems (e.g., to meet equal access requirements [Kellagher, 1987, pages 76, 84]).

The domination of the CO market by U.S. manufacturers[30] may be nearing an end, however. Several foreign manufacturers already have entered, or have announced plans to enter the U.S. market.

> "Manufacturers have responded to the BOCS' interest with large financial commitments to develop hardware and software sought by the major telcos. While most of the new entrants do not expect to overtake the two switching giants [ATT and NT], they nonetheless have begun to implement development and marketing plans that they hope will allow them to capture a sizeable share of the US market." [Kellagher, 1987, page 78]

One of the allegations of the antitrust suit against AT&T is that its standard practice procurement policy "foreclosed" other equipment vendors from the BOCs' market. If true, that would imply that one of the gains of divestiture is the additional incentive for competing telecommunications equipment manufacturers to invest in R&D in an effort to gain share in the RHC market. One possible concern - seldom expressed of late - was that the RHCs would continue to purchase disproportionately from AT&T Technologies (ATTECH, the former Western Electric).[31]

Indeed, AT&T continues to make substantial sales to its former operating companies, although the trade press reports few claims of "bias" in procurement policy. AT&T does own a substantial advantage, of course,

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[30] Northern Telecom's DMS-100 class 5 local COs are manufactured in the U.S.; Northern Telecom, Inc. is a subsidiary of Northern Telecom, Limited, a Canadian Corporation.

[31] This reasoning was based on the notion that tradition purchasing practices and "family ties" between Western Electric and the BOCs would be hard to break.

in having such a large share of the BOCs installed base. This advantage has several elements:

> BOCs' installation, operating and maintenance personnel have great deal of accumulated know-how about ATTECH (i.e., Western Electric) equipment;
>
> new AT&T equipment has a high degree of compatibility with installed equipment; and
>
> the BOCs are most likely to turn to ATTECH for expansion of or modifications to existing equipment.

In spite of these advantages, and AT&T's leading market share, there are countervailing forces at work. Again, the root of the problem is AT&T's unique position: it is the only company in the world with a substantial presence in both equipment manufacturing and telecommunications services that does not produce equipment primarily for its own use.[32] The RHCs, accordingly, have considerable incentive to develop relations with other suppliers.

Given that there are now only two U.S.-based companies producing large-scale digital switches (AT&T and GTE), both of which are competitors, we are not surprised that the RHCs are turning to foreign suppliers.[33] Foreign manufacturers of digital COs include: Northern Telecom of Canada; Alcatel-Thomson and CGE-ITT of France and Belgium; Ericsson of Sweden, Italcom/Telettra of Italy; Plessey/GEC/Stromberg of the UK;[34] Siemens of West Germany; Telenokia of Finland; and NEC, Fujitsu and Hitachi of Japan.

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[32] GTE is also vertically integrated between manufacturing and services, but most of its equipment is purchased internally, by U.S. Sprint and the General Telephone Operating Companies.

[33] Itec, Inc. and Rockwell International have also entered the CO market in the past two years; neither has yet to make significant inroads into the BOCS' market.

[34] Plessey purchased Stromberg-Carlson, then a U.S. company, in 1982, in an effort to gain a foothold in the U.S. markets for independent and REA telcos. Kellagher, 1987, page 81.

Northern Telecom and NEC have CO manufacturing plants in the U.S.; Siemens has a large R&D facility in Boca Raton (500 specialists working on central office switching systems).

B. R&D in the Telecommunications Equipment Industry

As shown in Table 1, foreign equipment manufacturers spend substantial sums on R&D. In comparison to IBM's R&D expenditures of 8% of sales revenues, the leading digital switchmakers spend from 6% to 16% of sales. These substantial expenditures on R&D reflect the rapid growth in the demand for telecommunications services. As Kline and Rosenberg have noted,

> "A rapidly expanding industry nearly always generates an increased demand on other industries that produce intermediate components and materials for it. This increased demand will often stimulate more rapid rates of technical change in these supplier industries." [Kline and Rosenberg, 1986, page 281].

Even so, the costs of developing a new switch, or upgrading an existing product are enormous. Estimates range as high as $1 billion to bring a new switch to market, with an additional commitment of $200 million per year in product development [Teece, Pisano and Russo, 1987].

As a consequence, switchmakers are expanding their geographic coverage (by adapting switches to new markets) to spread higher development costs and to realize growing economies of scale in R&D. The North America is particularly attractive, because it represents a substantial share of the world's total demand for COs.

In addition to geographic expansion (or, as part of their geographic expansion strategy), equipment manufacturers are increasingly turning to joint R&D ventures and strategic alliances, which cannot be explained by scale economies. Teece, Pisano and Russo argue that it is nature of the R&D process itself that is driving firms toward collaboration:

> "innovation in telecommunications equipment has become more tightly coupled to computer and microelectronic technologies. The resulting interdependence in design paths...make[s] it increasingly difficult and inefficient for the major equipment firm to track all the relevant technological fronts for themselves. As a consequence, they collaborate to gain access to complementary technologies." [Teece, Pisano and Russo, 1987. pages 38-9]

In their study of 117 joint ventures involving telecommunications equipment manufacturers, Teece, Pisano and Russo found a combination of technology access, distribution in strategic partnership (50 of 117 total cases involved distribution or cross-marketing, 15 of those also involved R&D or technology sharing). There were three main reasons:

> companies agreeing to integrate their product lines into a system (e.g., the AT&T and EDS agreement to develop and market specially designed computer and communications systems);
>
> a product must be modified for use in particular market, with local know-how required or advantageous; or
>
> production economics or political barriers dictate local production [Teece, Pisano and Russo, 1987. pages 35-37].

In 36 of 117 cases, joint ventures or sharing arrangement involved chiefly technology development or exchange. In addition to merging complementary products and technologies, Teece at al note the importance of higher development costs, in combination with shorter life cycles on the organization of R&D [Teece, Pisano and Russo, 1987, pages 24-5]. Kline and Rosenberg provide this explanation of the higher risks associated with rapidly changing technology:

> "...the very fact of rapid technological change itself raises the risk of investing in long-lived plant and equipment, since further technological change is likely to render such capital soon obsolete. If product life cycles are shorter... the agony of the risk-taking process in innovation is even further intensified...[as] the precise timing in the commitment of large amounts of resources to the development process has become even more crucial." [Kline and Rosenberg, 1986, page 301].

So, in order to realize scale economies by expanding geographically (joint technology/distribution ventures, to match complementary products and R&D skills, and to spread and share the risks of rapidly changing, high cost technology, most telecommunications firms are forming joint ventures, collaborative arrangements and strategic partnerships. As we will explain in Section V, the RHCs are notably absent from (or on the peripheries of) these developments, mainly because of the line-of-business restrictions. Instead, they must rely on their suppliers, many of whom are, or will be, foreign firms, a subject to which we now turn.

C. Vertical Relations between Carriers and Equipment Vendors

As noted earlier in this section, telecommunications equipment manufacturers spend heavily on R&D, several times, on average, what telecommunications services companies spend. Even British Telecom and NTT, which spend a considerably high portion of revenues on R&D than do the RHCs, spend less than their suppliers. This raises the question of the locus of innovation activity, and the role of upstream suppliers.

Nelson offers these insights on the respective roles of upstream and downstream firms in the innovative process:

> "an upstream firm's product is often an aspect of the user's process technology. Users may understand their own needs better than their suppliers, and may be active, therefore, in the product innovation business. The question of course is, how strong are their incentives to invest in such activity? If a particular user accounts for a large share of the market for the product in question, it may have considerable incentive. And if the technology of producing the product is relatively general, the user may rest quite content to make the product modifications it wants, and simply communicate these to its upstream suppliers, relying on competition in that industry, and its own monopsonistic position, to make this a low cost mode of supply." [Nelson, 1986, page 19].

But even when, as with the RHCs since divestiture, no single purchaser constitutes a large share of the total, so that the incentives

for innovation lie more with the suppliers, there are still plenty of reasons for upstream-downstream R&D cooperation, as suggested by Nelson:

> "Often the contribution of upstream firms comes in the form of standardized equipment or materials, but in many cases new equipment needs to be tailored to the particular idiosyncratic needs of the user. In addition, the user may need to modify other aspects of its processes or products in order to take advantage of the potentialities afforded by new materials or equipment. Under these circumstances, in-industry and upstream R&D are complements. The role of a firm's own R&D in enabling it to take advantage of the R and D done by others..." [Nelson, 1986, page 26].35

Even though the RHCs may have incentives for upstream-downstream R&D cooperation, there are appropriability problems inherent in such arrangements. Such "Williamsonian" problems (small numbers, opportunism) "are dampened by the promise of return engagements and the interests of both parties not to poison this possibility." [Nelson, 1986, page 27]. Even so,

> "...the downstream partner may not be able to control the manner in which the upstream partner deals with the downstream firm's competitors. The conditions in which these vertical arrangements thrive thus likely involve either strongly idiosyncratic process needs, or long term pairing, almost a vertical merger, of upstream and downstream firms, or acceptance in the downstream firm that the kind of process technology being worked on will not be a competitive item strongly differentiating firms in that industry." [Nelson, 1986, page 28].

What do these factors, taken together, imply for the RHCs? They have, first, a strong interest in achieving as much compatibility among as many alternative suppliers as possible, to avoid potential lock-in problems

35 Teece has expressed the need for in-house R&D in procurement in these terms:

> "Indeed, when the procurement of technologically-advanced products and services is contemplated, the key organizations responsible for delivering advanced products and systems will need to have an in-house research and development capability." Teece, Forthcoming, page 13.

of becoming dependent on one or a few vendors.[36] Second, they need a high level of knowledge about the offerings of the vendors, in order to keep up with rapidly changing technologies; that requires in-house (including Bellcore) know-how and some joint R&D with upstream suppliers.[37] Third, given that Bellcore and the RHCs are strictly limited in their ability to appropriate the benefits of their own R&D,[38] they have a strong incentive to be as open as possible. Bellcore's efforts to develop system standards and serve as clearinghouse for vendors' product offerings, will surely increase the rate and degree of spillover among equipment makers.

Where do these factors collectively lead the RHCs: to foreign manufacturers of telecommunications equipment. Both through increased purchases of their products, through the testing, evaluation and design services of Bellcore and the individual RHCs, and through joint R&D ventures (e.g., Pacific Bell and NEC), we expect divestiture to be a real boon for foreign equipment producers.[39] While liberalization of

[36] A particularly interesting example of the RHCs seeking to minimize dependence on AT&T for equipment is Pacific Bell's venture with NEC: 80% of PacBell's customers on 1AESS switches (a Western Electric analog electronic switch); Pacific is working with NEC to test a "digital adjunct" that would provide ISDN to those customers Marano, 1987, page 88.

[37] Hence, Bellcore's role in evaluating vendors' offerings: "Many of the BOCs have requested Bellcore... to begin evaluating the switching systems of all of the suppliers against Bellcore's requirements." Kellagher, 1987, page 78. Even then, "passive reliance on supplier industries leaves the rate of innovation beyond the influence of the downstream firm." Teece, 1981a, page 20.

[38] They cannot expand geographically (in the provision of local network services); they cannot vertically integrate; they can license.

[39] Moreover, Judge Greene has ensured that the foreign vendors will gain a disproportionate share of the

telecommunications policies is occurring elsewhere, it seems highly unlikely that foreign markets will open nearly as fast or as much as the U.S. market has. The most one could hope for is a reduction in the favoritism shown to national suppliers by other nations PTTs.

V. THE EFFECTS OF PUBLIC POLICIES

In previous sections, we considered the effects of the divestiture itself on R&D and innovation by the RHCs. We turn now to the implications of the line-of-business restrictions imposed by the MFJ for the RHCs' incentives, organization and probability of success in R&D activities. Although not part of the consent decree, we also discuss the implications of the FCC's Open Network Architecture requirement (in the Computer Inquiry III decision) and the treatment of R&D expenditures by state regulatory commissions under rate-of-return regulation.

A. Effects of the Line-of-Business Restrictions

The line-of-business restrictions (LOBRs) are intended to prevent the RHCs from exploiting their market power in local access to compete unfairly in related markets. The Court has been willing to approve waiver requests

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benefits of joint ventures with RHCs by restrictions placed on foreign business waivers:

> "The Products or services of the ... foreign businesses...shall be sold for use or consumption solely outside of the United States, Canada... shall not provide or have a financial interest in telecommunications that originate or terminate in the United States. Ameritech ...will not sell import or use telecommunications products or CPE manufactured in whole or in part by one of its foreign businesses... If any Ameritech foreign business utilizes patents, software or other technology sold or licensed to it by Ameritech, then the operating telephone company...will make the patents, software or other technology. Order of the U.S. District Court, June 26, 1986.

for business activities that do not have a high degree of "relatedness" to the RHCs' core business,[40] and has, in its most recent order and opinion [Order in Civil Action No. 82-0192, September 10, 1987, eliminated the structural separations requirements from such waivers.

But of principal concern here are the continuing LOBRs on RHC involvement in manufacturing or enhanced information services. While these limits may provide incentives for other parties (e.g., potential enhanced services vendors) to invest in R&D, we are interested in the effects of the limitations on the RHCs' incentives for, and on the returns to, R&D expenditures (i.e., successful invention and/or development of commercialized products and services). On three main counts, we think the LOBRs will have strong negative effects on innovation:

> (1) they prevent the use of (and thereby discourage efforts to develop) innovations that exploit economies of scope in central office switches (especially the LOBR on information services);
>
> (2) they decrease the incentive for RHC investment in R&D by curbing the appropriability of R&D results (by reducing the scope of applicability in commercialization); and
>
> (3) they lower the odds of successful innovation by inhibiting learning by doing and learning by using (especially the LOBR on manufacturing).

Note that while the second impacts only the RHCs, the first and third also effect other actors (e.g., by making joint ventures with manufacturers difficult, each potential joint venturer loses some of the potential benefits of learning by using).

Before expanding these points it is important to note that the LOBRs are not only organizational restrictions: they do not merely limit the scope of RHC activities. They are - first and foremost - limits on the use

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[40] The Court has approved virtually all such requests, albeit with conditions attached. U.S. Department of Justice, May 8, 1987.

of technology. A switch that is capable of offering both local access and enhanced information services could be used anywhere else in the world, but not in the U.S., so long as the LOBRs are in place.[41] The LOBRs effectively "force" technology up (to the tandem switches of the IECs), down (to the CPE and PBXs of customers) or sideways (to the equipment of third party providers).

Of course the MFJ cannot control all technology - only its application in the U.S. Since the PTTs of the world have a definite interest in integrating as much functionality into the switch as possible, the MFJ has set the U.S. on a course distinctly different from - if not directly at odds with - the overall path of technological change. Given that PTTs are fully integrated between local and long distance and across "basic" and "enhanced" services, they have fundamentally different interests than the RHCs in the international standards now being developed. They will, moreover, play an influential - if not determinative - role in that process:

> "By virtue of the leverage they are recognized to possess within the domestic arena, and the potential influence they may exert over the terms of international competition through advocacy of particular standards. it is thus to be expected that individual government agencies will become entangled thoroughly in dynamic market rivalries between sponsored-system standards." [David, 1986, page 47]

We expect the PTTs to use their leverage to support standards that favor integration of the network, as opposed to the disintegrated approach being pursued in the U.S. If they succeed, the most we can hope for is that technological gains abroad will have limited transferability to the

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[41] With the exception of the independents, including GTE, which are not bound by the MFJ.

U.S. (and vis versa). The worst outcome is that, due to a standards impasse, the U.S. finds itself at odds with world standards.

Another effect of the LOBRs is on appropriability, and thereby on the incentives for RHC R&D. It is widely appreciated that a company (joint venture or cooperative) can maximize return on its R&D investment only if it can commercially appropriate a sufficient amount of value from innovations produced by the investments. The LOBRs make it difficult for an RHC to commercially appropriate any innovation that relates to the design of new telecommunications equipment or information services [Markey and Blau, 1986, page 3].[42] This is ironic, since the RHCs hold one key ingredient in appropriating returns to innovation, complementary assets [Teece, 1986, pages 288-90].

While "the generally accepted model of innovation proceeds linearly from scientific research to development, development to production and production to marketing," [Aoki, 1987, page 10], we agree with Kline and Rosenberg's "chain-link model" of innovation [Kline and Rosenberg, 1986]. In their view, feedback is critical to the innovative process; interaction among research, development, production, distribution and marketing all generate knowledge and understanding.

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[42] Markey and Blau have made the point in these terms:

> "Because line-of-business restrictions embodied in the AT&T consent decree prevent the Bell companies from recovering R&D costs, the decree virtually eliminates financial incentives for the RHCs to invest in R&D. In time, current disparities in R&D spending by the RHCs and major multinational full-service vendors (such as AT&T and IBM) also will result in a more concentrated, less competitive domestic telecommunications and information market structure." Markey and Blau, 1986, page 5.

The LOBRs, of course, greatly limit the amount of feedback by prohibiting manufacturing activity and inhibiting joint ventures with manufacturers.[43] The PTTs are not so limited, however; while few are vertically integrated into manufacturing,[44] they are heavily involved in collaborative research and joint ventures with equipment manufacturers. Indeed, that is one major benefit of the historic practice of each PTT buying mainly from its nationally favored supplier: it generates the feedback and appropriability benefits of quasi-integration (while also denying themselves the benefits of international competition).

B. Open Network Architecture

Bellcore has devoted substantial resources to work on ONA, particularly on the "Intelligent Network (IN/2) concept that is the heir apparent to the Feature Node/Service Interface model. In large measure it was this model that captured the FCC's imagination in the Computer III proceeding and resulted in the ONA regime being handed down as the law of the land." [TELECOMMUNICATIONS, January 1987, page 63]. While critically important to the RHCs, they are hypersensitive about this work because they "want to avoid becoming trapped into having IN/2 implementation become a *quid pro quo* either for structural separation relief under the Computer III

[43] Wallich [1985, page 92] has noted the contrast between the RHCs and AT&T on this count:

> "Bellcore cannot work as closely with a development and manufacturing group as the old Bell Labs did, or as AT&TBL does, thus depriving it of feedback.

[44] Nor would we expect the RHCs to be if the LOBRs were removed; we would expect a much higher level of joint R&D and other forms of joint ventures and collaboration between RHCs and telecommunications equipment manufacturers.

regime or for line-of-business relief in the divestiture proceeding." [Rutkowski, 1987a, page 68].

While the RHCs all support this work on ONA, there are significant differences among them. Hence, it is reported that "each intends to project its own unique related identity...[so] Bellcore's official position is one of substantive neutrality on most visible ONA issues." [TELECOMMUNICATIONS, January 1987, page 63]. These dual forces, the need for standardization combined with a desire for RHC independence, are driving the technology process:

> "Intense R&D in Bellcore is now occurring to devise a stable, universal set of FC's [functional components, which serve as "network macros"]. The IN/2 approach is a highly flexible distributed network architecture that allows services to be provided in a variety of physical network configurations, under the control of many different entities... the personnel of the operating telephone company can write their own service provisioning programs - a factor repeatedly emphasized during the presentations. [E]ach RBOC is seeking to be individually innovative and distinctive. Those present seemed aware that an appropriate balance between these competing concerns was necessary." [Rutkowski, 1987a, pages 70, 72

Again, public policy is imposing constraints on technology, not merely on the scope of organizations' activities. In combination with the LOBRs, ONA is setting the U.S. on a technological course that is quite different from the rest of the world. In the nations with intense R&D efforts by PTTs and telecommunications equipment manufacturers, the innovation process is directed, at least in large part, toward integrated systems solutions. Even where competition is now allowed, other nations are not restricting their PTTs or their technology in providing telecommunications services.

C. Rate Base Regulation

Although Bellcore is not itself regulated as a common carrier, its budget is nonetheless subject to regulatory scrutiny by the state PUCs. In some cases, RHC payments to Bellcore were disallowed by PUC's, on the grounds that "Bellcore's applied research... strayed too far afield from local phone service, [so] Bell shareholders ended up with the bill." [BUSINESS WEEK, December 2, 1985, page 106].

In California, for example, the Public Staff Division has proposed disallowing $30 million of Pacific Bell's roughly $100 million contribution to Bellcore. Similarly, a National Association of Regulatory Utilities Commissioners study raised questions about $115 million of operating company support for Bellcore, contending that

> the primary beneficiaries of Bellcore applied research were manufacturing companies rather than the local operating companies, and therefore the ratepayers should not bear the costs... 'If the manufacturers turn out better, cheaper products, then the operating companies and the ratepayers benefit,' said a Bellcore spokesman." [Wallich, 1985, page 96].

There are several important implications of this treatment of R&D expenditures by the PUCs. First, it explains much of the uncertainty that Bellcore employees are reported to feel [Wallich, 1985, page 96].

Second, given that oversight by PUCs, it would be "imprudent" for the RHCs to publicly express dissatisfaction with Bellcore's research, since state regulators might use such statements to justify disallowances and rate reductions [Roberts, 1987a, page 5].

VI. CONCLUSIONS

The divestiture of the Bell operating companies has not only altered the structure of telecommunications in the U.S. It has fundamentally shifted the course of technological development. The divestiture and

conditions imposed by the MFJ on the RHCs have reduced the incentives for RHC R&D by restricting the appropriability of innovations. The vertical disintegration of the RHCs from manufacturing greatly reduces the feedback between R&D, manufacturing and marketing that is often critical to successful innovation. Perhaps most importantly, the MFJ, along with ONA, has set the course of U.S. technology on a trajectory that is quite different from - if not at odds with - the path that other nations will likely follow.

On the other hand, divestiture has set off a great wave of competition among equipment makers, especially those vendors attempting to replace - if only partially - AT&T as a supplier to the RHCs. There are abundant signs that this competition has been healthy for AT&T itself, as pressures from foreign manufacturers entering the U.S. market (and opportunities for AT&T abroad) stimulate much more market driven product development activities.

On balance, it seems that, at least in the short to medium run, divestiture had positive effects on technological innovation in the telecommunications industry, especially if viewed from a global perspective. From a nationalistic perspective, the answer is less clear. Certainly foreign equipment manufacturers are among the biggest winners and - so long as the line-of-business restrictions remain in place - the RHCs are among the biggest losers.

The lesson of all this, unfortunately, is how little such dynamic, technological considerations seemed to play in the MFJ decision and concomitant public policy debates. Even accepting the proposition that vertical and horizontal disintegration of AT&T produced static efficiency gains by promoting competition and driving prices toward costs, there

remains an open question as to the costs of divestiture in terms of dynamic efficiency.

The only advice we offer at this junction - specific policy recommendations aside - is that the Court, the FCC, the state PUCs, and, perhaps ultimately Congress itself, elevate the importance of technology and innovation in the policy-making and implementation processes. One step in that direction is a transfer of jurisdiction over telecommunications policy from a District Court to regulators. Under antitrust standards, it is highly unlikely that technological innovation and national competitiveness will receive the weight they deserve in that decision-making process. Under the public interest standards of regulation, there is some chance they will.

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